SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

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FEBRUARY 1958—VOL. 30, No. 2

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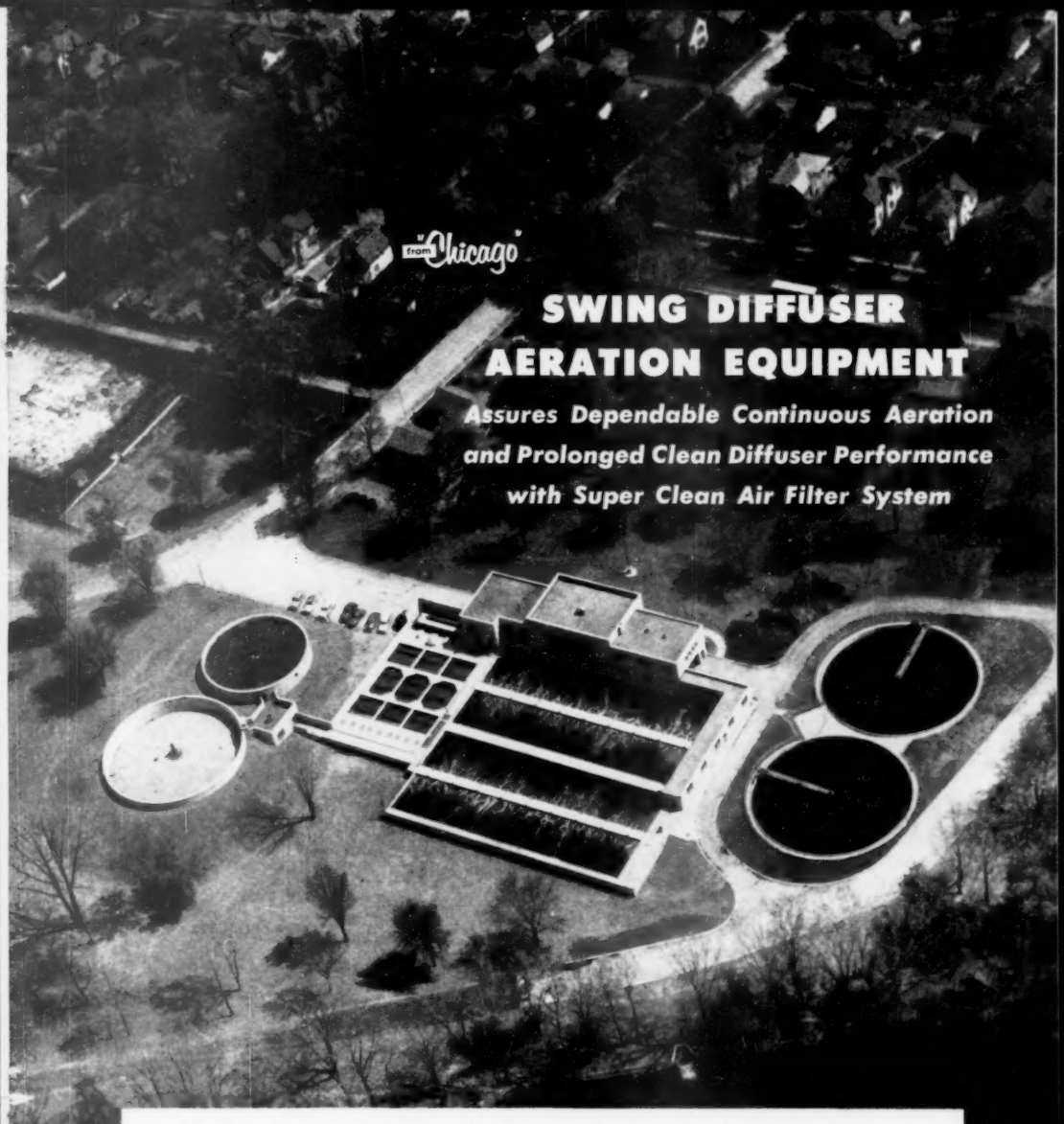

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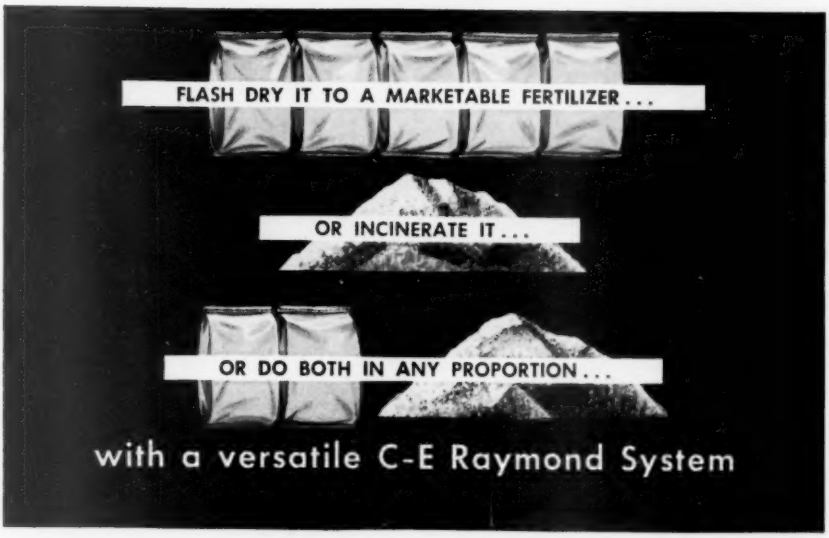

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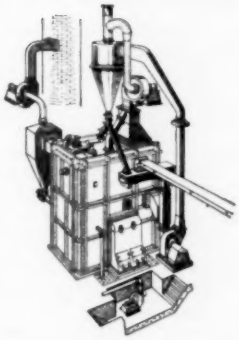

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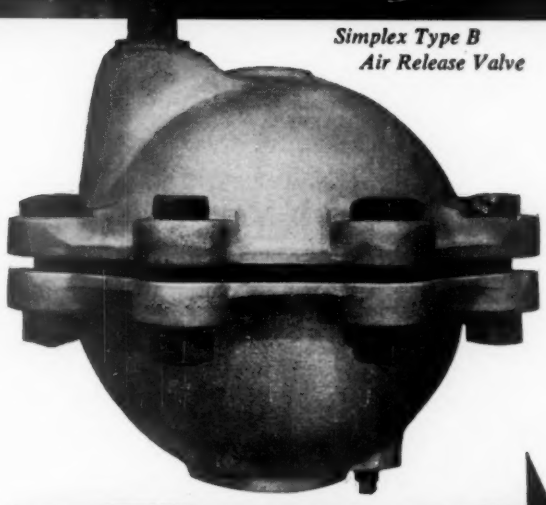

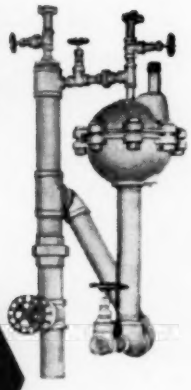

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Association	*Place*	*Time*
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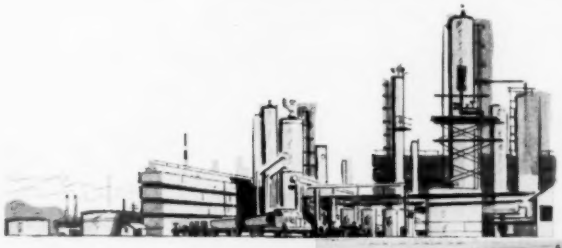
Texas Water and Sewage Works Assn.	Texas A & M College College Station, Texas	Mar. 2–7, 1958
New Jersey Sewage and Industrial Wastes Assn.	Traymore Hotel Atlantic City, N. J.	Mar. 12–14, 1958
Louisiana Conference on Water Supply and Sewerage	Louisiana State Univ. Baton Rouge, La.	Mar. 12–14, 1958
Kansas Sewage and Industrial Wastes Assn.	Lamer Hotel Salina, Kans.	Mar. 12–14, 1958
Montana Sewage and Industrial Wastes Assn.	Florence Hotel Helena, Mont.	Mar. 20–22, 1958
Arkansas Water and Sewage Conf.	Univ. of Arkansas Fayetteville, Ark.	Mar. 24–26, 1958
California Sewage and Industrial Wastes Assn.	Hotel Stockton Stockton, Calif.	Apr. 23–26, 1958
Virginia Industrial Wastes and Sewage Works Assn.	Hotel Roanoke Roanoke, Va.	Apr. 28–29, 1958
Central States Sewage and Industrial Wastes Assn.	Purdue Univ. Lafayette, Ind.	May 5–7, 1958
Arizona Sewage and Water Works Assn.	El Conquistador Hotel Tucson, Ariz.	May 15–17, 1958
Sweden (Foreningen for Vattenhygien)	Consert Hall Oerebro, Sweden	May 16–17, 1958

THIRTY-FIRST ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Michigan Sewage and Industrial Wastes Association
Sheraton-Cadillac Hotel, Detroit, Michigan
October 6–9, 1958



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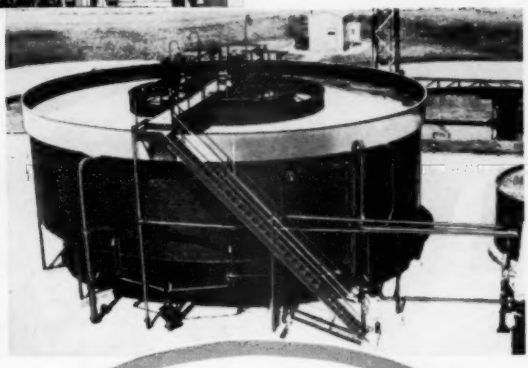

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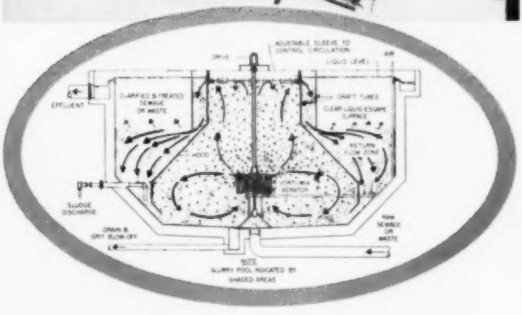

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1978 WATER

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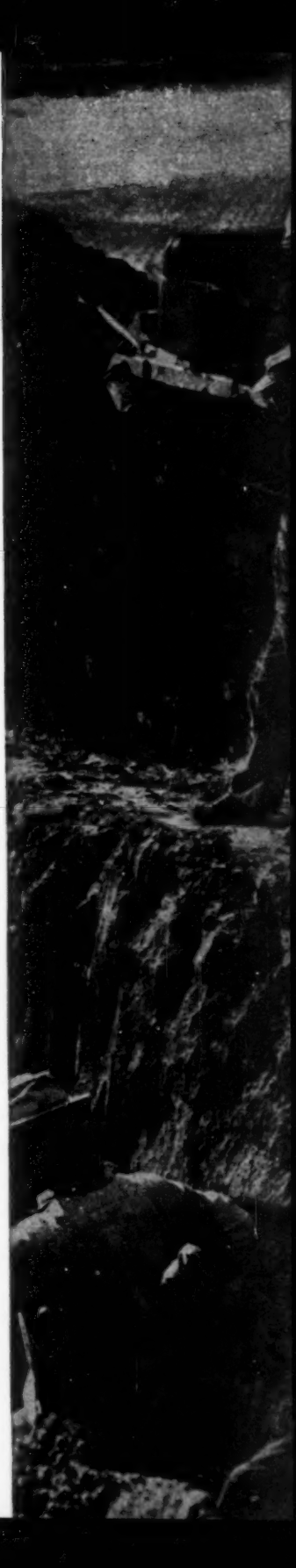

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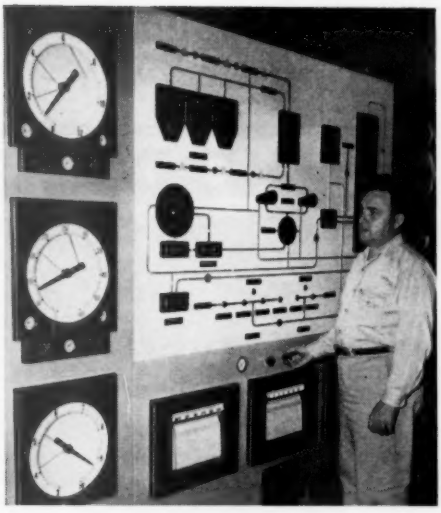

Semi-graphic panel clearly associates chart readings with the process, so that even an inexperienced operator can easily ◀ supervise the plant.

Brown pressure recorder at main pumping station records pressure head on mains to treatment plant and transmits measurements to graphic panel. ▼

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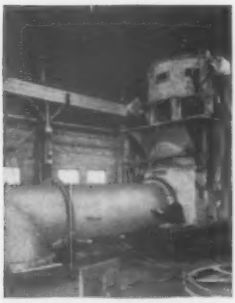

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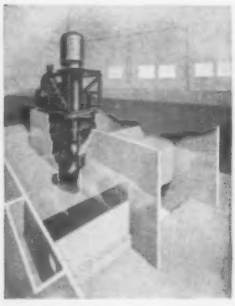

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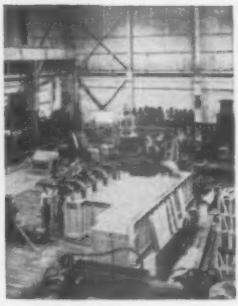

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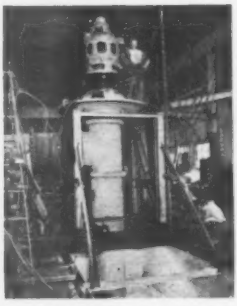

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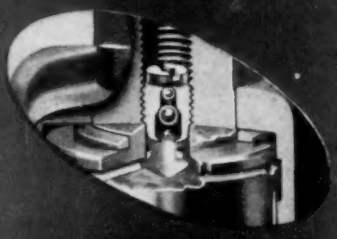

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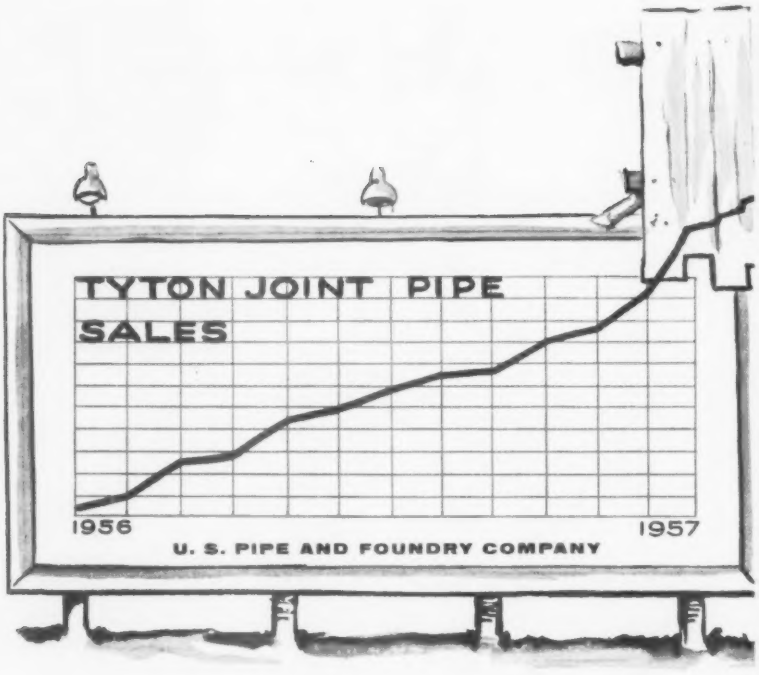

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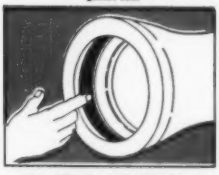
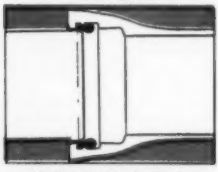
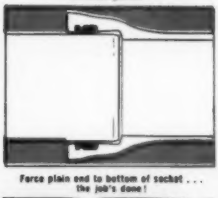


Wipe a film of special lubricant over inside of gasket

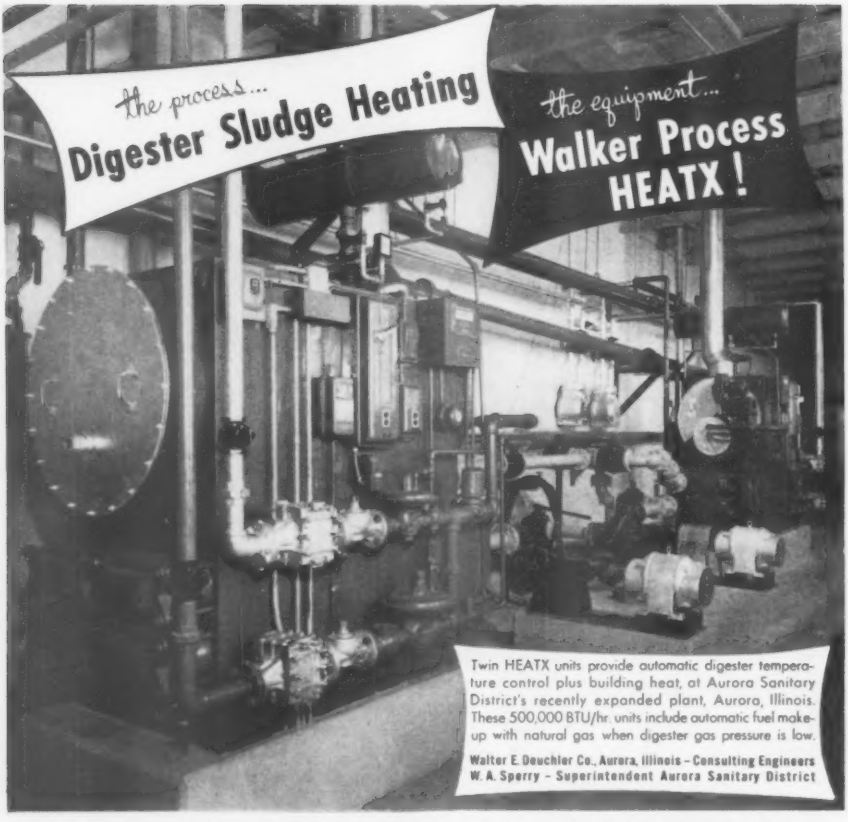


Insert plain end of pipe until it contacts gasket



Force plain end to bottom of socket . . . the job's done!

20" Tyton Joint pipe being installed for water supply line in Alabama.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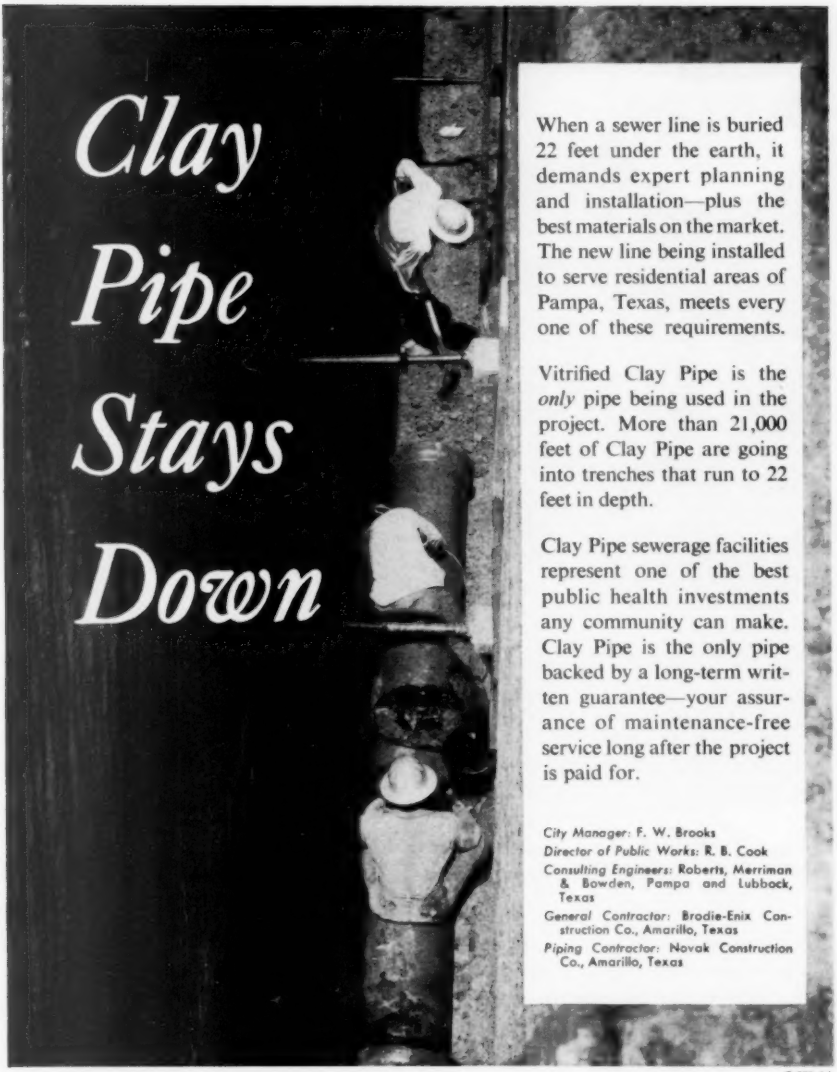

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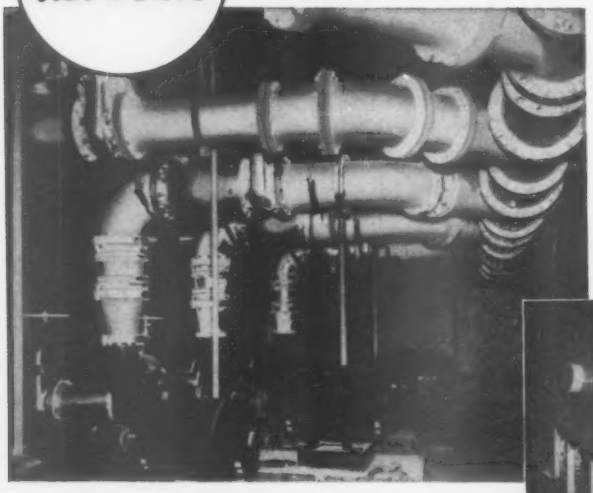

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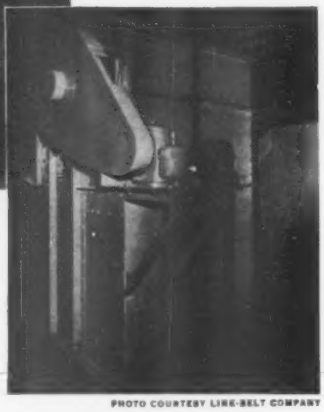

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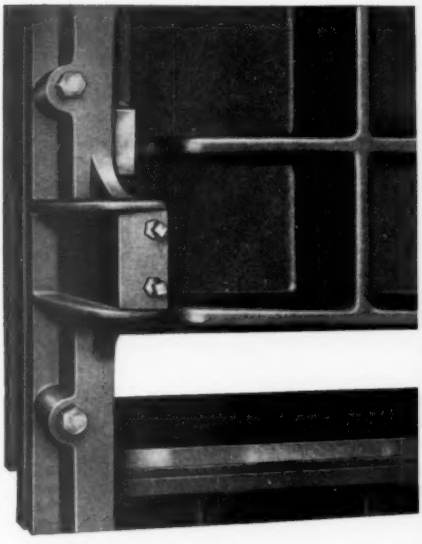
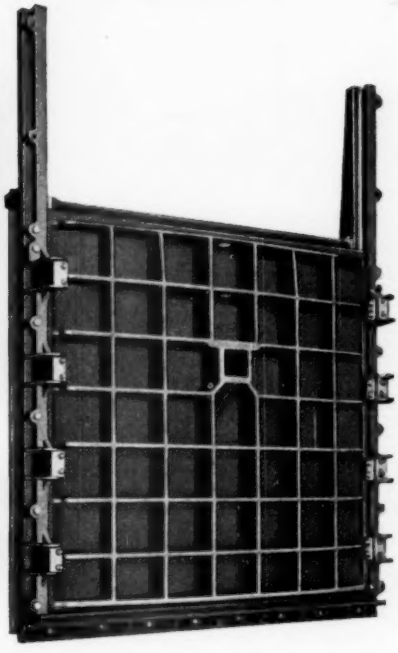


Close-up view of flush bottom opening.



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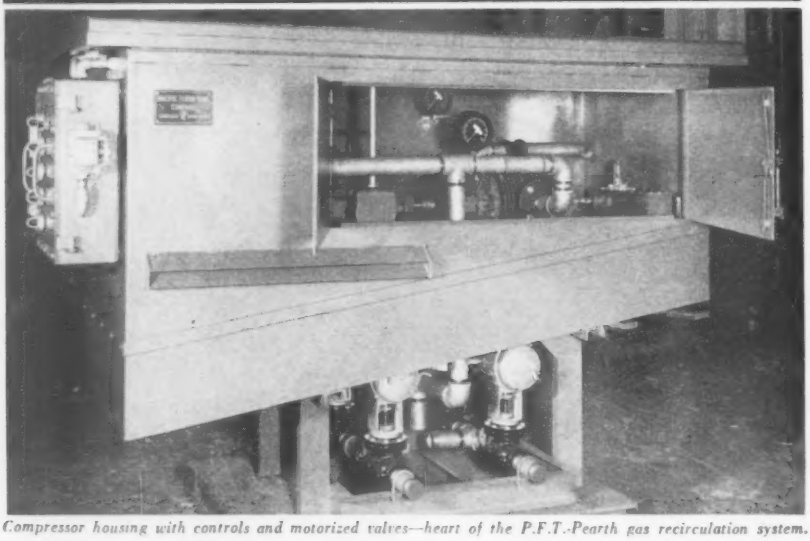

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 30 **February 1958** **Number 2**

Contents

Sewage Works

Municipal Financing of Sewerage Facilities. By JAMES J. FLANNERY 123

Application of Molecular Filter Techniques to the Bacterial Assay of Sewage. II. Experimental Results for Settled Sewage. By JACK E. MCKEE AND RONALD T. MCLAUGHLIN 129

Continuous Sampling of Trickling Filter Populations. II. Populations. By WM. BRIDGE COOKE AND ALAN HIRSCH 138

Variation of Sewage Flow in a College Town. By GARY D. HUTCHINSON AND E. ROBERT BAUMANN 157

Studies on Sludge Digestion and Methane Fermentation. II. Methane Fermentation of Organic Acids. By K. L. SCHULZE AND B. NAGA RAJU 164

Industrial Wastes

Foul Condensate Treatment and Disposal. By ORSANCO Oil Refining Industry Action Committee 185

Phenol Recovery by Use of Isopropyl Ether. By NORBERT H. KIRCHGESSNER 191

Combined Treatment of Industrial and Domestic Wastes. By L. S. KRAUS 199

Discussion by JOHN J. CURRY 205

Stream Pollution

Biochemical Degradation Products—A New Dimension in Stream Pollution. By R. H. BOGAN 208

Basic Data for Water Supply and Water Pollution Control. By RICHARD S. GREEN 215

The Operator's Corner

Removal of Sewer Odors by Scrubbing with Alkaline Solutions. By C. W. BEARDSLEY, N. J. KROTINGER, AND J. H. RIGDON 220

First-Year Operating Experiences at Sacramento, California. By HAROLD H. JEFFREY 225

Whirling Dervish Stopped. By CEDRIC WEBSTER 236

Three-Year Summary of Operation, Blasdell, New York, Sewage Treatment Plant. By STANLEY J. PIECZONKA 237

Tips and Quips 239

Editorial

1957 Growth in Member Associations 241

News and Notes 242

Reviews and Abstracts 243

Proceedings of Member Associations

Georgia Water and Sewage Association 64a

North Dakota Water and Sewage Works Conference 64a

South Dakota Water and Sewage Works Conference 66a

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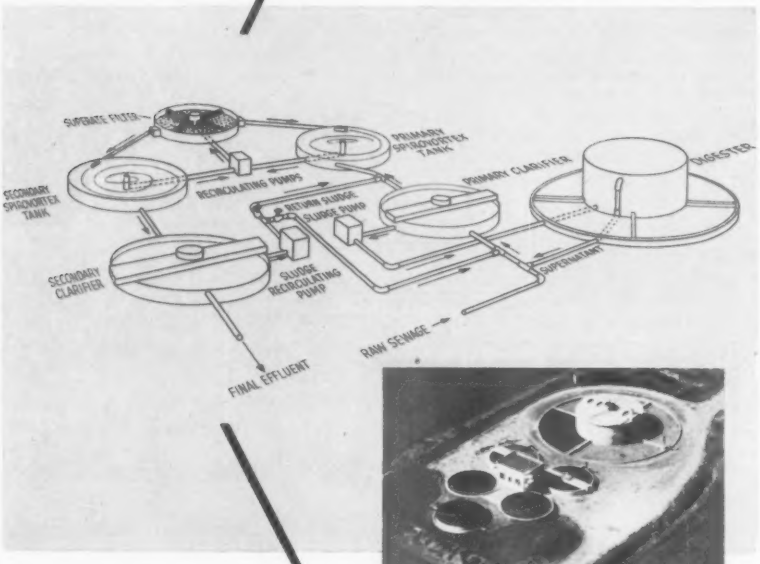

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Sewage Works

MUNICIPAL FINANCING OF SEWERAGE FACILITIES *

By James J. Flannery

Economist, Water Supply and Water Pollution Control Program, USPHS, Washington, D. C.

The proper apportionment of the costs of government among the members of the community is one of the major problems of democratic government. This problem is important at all levels of government, at the local as well as the national, for in each instance basic questions of justice are involved. At the local level, however, in contrast to the federal and state levels, the problem is somewhat less complicated because the benefits accruing from and the services provided by local governments are identifiable to a considerable degree. This feature of identification facilitates the application of the principles of public finance—those tenets or fundamentals that provide the rationale for decisions in regard to the financial aspects of government.

Cost Responsibilities

The principles that are generally considered to be the most applicable in the determination of the basis for the apportionment of governmental costs are:

1. That those who benefit from an activity bear the cost.
2. That those who use a service bear the cost.
3. That those who have the ability to pay bear the cost (because membership in society is compulsory and the obligation to support the state rests upon all who have the resources to contribute).

The last principle, although of considerable importance in the underlying foundation of state and federal taxation, has little direct application to local government situations. Therefore, only the other two principles, the benefit principle and the service principle, are of interest to this particular local government activity—the provision of sewerage facilities.

Financing Background

In order to understand the application of the basic financing principles to this problem it must first be noted that sewerage systems historically were classified as "governmental" functions, as contrasted to "proprietary" functions, because sewerage systems were established to protect the health of the entire community and because there was little prospect of their operation as a private endeavor. The distinction between "governmental" and "proprietary" functions arose from the necessity of establishing the extent and nature of governmental immunity from legal suit. The distinction is no longer of much importance in the determination of the method for apportioning the costs of municipal services. The rationale of the early period required that the costs of "governmental" functions be borne by the entire community without distinguishing the extent of benefit or use among individual members of the community because such functions were of general, community-

* Presented at the 1957 Annual Meeting, Texas Water and Sewage Works Assn., Short School, College Station, Texas; March 3–8, 1957.

wide benefit. The costs of "proprietary" functions, on the other hand, such as municipally-owned gas works, power plants, and perhaps waterworks were intended to be apportioned among the users according to an extent-of-use basis as in normal private enterprise operations. Placing sewerage systems among the "governmental" functions, therefore, limited cost apportionment doctrine to the benefit principle and restricted the application of the use principle. No immediate difficulty was encountered on this account, for the costs of the sewerage function were not particularly high and the revenue from the general property tax was more than adequate to meet the financial requirements. Some variations in the financing arrangements arose, however, in those instances where the entire community was not served by sewers. Special benefit assessments were used for those who had access to the sewers, and some states allowed the municipalities to levy sewer service charges.

Sewer Service Charges

Little attention was given to the development of an adequate rational foundation for the service charge during the early period. Indeed, discussion of the subject was confined chiefly to the law courts in suits filed by taxpayers protesting the levy. These protestants complained that they had already paid for sewerage facilities through general taxation and special assessments; therefore, that service charges were discriminatory and confiscatory without the observance of due process of law. One of these cases, involving the city of Brockton, Mass., reached the Supreme Court of the United States in 1901.* The Court said that no violation of the U. S. Constitution was involved and upheld the city of Brockton and the Massachusetts statute authorizing the city to levy the charge. The Court's opinion indicated that it considered the service charge to be a measure of continuing special benefits arising from use. In fact, the Court in expressing this viewpoint quoted the following from the opinion of the Chief Justice of the Massachusetts Court, who had upheld the statute and the city when the case was before him for decision: †

> If building the sewer was of special benefit, keeping the sewer in condition for use by such further expenditure as was necessary was a further special benefit to such as used it. . . . The charge allowed by the Act is a charge for using the sewer—a benefit distinct from that originally conferred by building it.

The reasoning of both the U. S. Supreme Court and the Massachusetts Supreme Judicial Court apparently was influenced by the traditional view that sewerage service was a "governmental" function and therefore, that the service charge, if it were to be sustained, must be related to special benefits because the general benefit already had been paid for through community-wide general taxation. Thus, no attempt was made to distinguish between the concept of use and the concept of benefit. This omission acted to the detriment of municipal financial policy later on when a rationale establishing the service charge clearly on the basis of use and independent of the benefit concept was needed. Although it appears that the Court easily could have clarified this situation by justifying the service charge as merely the price for which sewerage service was sold, such a conclusion evidently could be reached only if sewerage service were regarded as a proprietary function. The case is cited to reveal the historical and legal trammels impeding the adoption of the service charge.

Municipal Considerations

Municipalities began to recognize these impediments when sewage treat-

* *Carson v. Brockton Sewerage Commission* 182 U. S. 398.

† 175 Mass. 242 (56 N.E. 1).

ment as well as mere disposal became necessary to protect the public health. In other words, municipalities were incurring the costly addition to their responsibilities of the construction and operation of sewage treatment plants at a time when the application of the most feasible method of payment, the sewer service charge, was restricted by historical and legal factors. The condition was accentuated by the impact of the depression with its attendant decline in property values and large volume of real estate tax delinquencies. The reliability of the general property tax as the single major source of municipal income was thus undermined; therefore reappraisal of the entire structure of municipal finance became imperative. In contrast to the generally uncertain financial picture of local government, the financial stability of municipal waterworks during the period was impressive; and it became more or less evident to municipal officials that sewerage service, especially sewage disposal, was similar in many respects to waterworks operation and might be financed in the same way. The financial strength of the waterworks, derived from the essentiality of water service and the authority of the municipality to shut off the water to users who became delinquent in water bill payments, was an attractive possibility. The collection of delinquent property taxes was a much more difficult matter since the remedy consisted of a tax lien or forced sale in what was then a depressed real estate market. The unpopular moral and political implications, as well as the impracticality, of collecting or compensating for delinquent taxes through what would amount to mass sales of residential and other property tax liens left municipal officials most reluctant to undertake this tactic. To alleviate these financial and administrative difficulties, sewerage facilities came to be regarded and operated much as utilities, with some version of a service charge providing the chief financial support. This arrangement offered the twofold possibility of facilitating sewerage financing and providing some relief from the burden of taxation on property.

State Legislation and Interpretation

Since municipalities are creatures of the state and possess only those powers expressly granted to them, no municipality could resort to sewer charges without obtaining the necessary authorization through the state legislatures. Much of this legislation was challenged in the state courts by those who were paying more for service under the new systems than the old. The state courts in general upheld the statutes, but because of the extreme diversity in the content and scope of these statutes, the case law resulting from judicial rulings is not uniform among the states. Despite the lack of uniformity, the generalization can be made that the courts' acceptance of the use of the service charge by a municipality is dependent upon the specific legislative authorization involved. That is, municipal action in this field will be sustained by the courts as long as it coincides with the intent evident in the enabling legislation.

At this point it is well to note that service charges are not "taxes" in the strict sense. "Charges" are much closer to "prices" in that the payments are intended to cover at least some of the economic costs of providing the service. When this viewpoint is followed the system becomes more intelligible and decisions in this respect are disencumbered from historical limitations. The advantages of this development can be observed in those states where the courts have been able to disregard the concepts of "proprietary" and "governmental" in considering payment problems. In these instances the courts can consider the issues from the standpoint of broad public policy and the most effective and equitable solution.

Rate Determinations

The mere acceptance of the sewer service charge as the basis for the system of sewerage financing did not automatically assure an equitable apportionment of the costs among the users. Many of the court cases involved this point—the equitability of the schedule of charges and the measurement of use. It was generally agreed that the service charge would constitute the price paid for the use and that these receipts were to cover normal operating and maintenance costs. It was also agreed that the price or charge was to be determined by the amount of use and possibly by the strength of the wastes discharged into the sewer. The amount of use was to measured as a percentage of the water bill or by the number of connections to the sewer or by some other reasonable means. The courts have upheld each of these measures when it could be demonstrated that the extent of sewer use was reasonably indicated in that manner. A more difficult measurement problem arises in determining the strength of the wastes, but sanitary engineers are now able to calculate the burden of various organic wastes on both structure and process within the treatment plant. This determination is usually done through the cooperation of the sewer users and the municipal officials.

Capital Cost Financing

Agreement that operating and maintenance costs should be covered by service charges is virtually universal. However, there remains the question as to whether capital costs can reasonably be covered by service charges. Experience indicates that in many instances such costs are being included, especially where the plant is being financed by revenue bonds. The consulting engineer's role is vital in the determination of the schedule of charges in this regard; he provides the information on volume and strength of sewage from each category of user and the relationship of structure and process to these categories. The development of this type of charge schedule is probably easier to achieve for new plant construction than for older plant refinancing because the resistance-to-change factor is redoubtable in the latter case and virtually absent in the former.

Special Benefit Assessments

The inclusion of capital costs within the scope of the service charge does not prohibit the added use of special benefit assessments and general taxation. Special benefit assessments may be levied to cover some of the costs of collection system extensions. Special benefit assessments are levied against property peculiarly benefited by a governmental operation. Thus, vacant land and other undeveloped property can be included even though not connected with the sewer because the special benefit assessment is levied against the increase in value that occurs due to the availability of the sewerage system.

General Taxation

Because the presence of a sewerage system is considered to be of general benefit to the community, some portion of the capital cost justly can be recovered through general taxation. This conclusion is reached on the ground that general taxes; i.e., property, income, and sales taxes, are used to pay for those governmental operations which are of general benefit to the community and for which the extent of individual benefit is impossible to determine. The tax burden for the general benefit associated with sewerage facilities need no longer be viewed as a levy against property alone. Taxes such as sales or income can be utilized validly in this respect, for the broadness of their base may be more closely related to the general public than is the property tax. Furthermore, sales and income taxes may be collected from non-resident as well as resident users.

New Sewer Connection Fees

Another source of revenue used in many jurisdictions is the fee charged for each new connection to the sewer. Although this fee is intended to defray the actual cost of making the connection, it is often set to produce an income substantially beyond the costs involved. It may be helpful to consider the differences between "charges" and "fees." "Charges" are the prices paid for services on the basis of the extent of use. "Fees" are the prices for the services of officials and are also paid for by the user.

Equitable Cost Apportionment

This list of possible means for collecting the costs of sewerage facilities may appear to lay emphasis only on how to raise money, but the real objective of the discussion is to point the way to the attainment of equitableness. This objective is particularly difficult when an existing plant has been financed from general taxation, and the decision is then made to adopt sewer charges that will cover future capital costs as well as operating costs. When this situation occurs, the areas of the community that have already paid for capital costs can be determined. This information will form the basis for apportioning new capital costs. It is not necessary, however, that new areas or subdivisions bear the entire cost of additions either to collection systems or to treatment works, for the entire community benefits to some extent from the improvement. Instead, the objective of the apportionment should be to assure that no area is exploited at the expense of another. Such situations arise occasionally when metropolitan districts are formed, when municipal annexations take place, or when new subdivisions are served. The problem will yield to analysis, however, and when the three forms of cost apportionment are utilized—the service charge, the special benefit assessment, and general taxation—an equitable solution can be attained. For instance, the schedule of sewer service charges may be established to allow an area differential to take account of the extent to which the areas have contributed to the capital costs of existing structures. This variation and other similar adjustments can be made on the basis of local standards, procedures, and preferences.

The provision of sewerage service for the urban fringe and other more or less populous areas near central cities is as much an organizational problem as it is a financial management and engineering problem. That is, a decision must be made as to the extent of the area to be served, considering whether the area can be most efficiently (in both the engineering and the economic sense) served by connection with existing systems, establishment of new sewerage districts, the use of so-called package plants, or some other means. Analysis of the revenue situation for each possible organizational plan and the appraisal of the cost apportionment problems under each will be necessary for decision.

Storm Sewer Theories

It has been suggested periodically that the cost of storm sewers can be included within the regular financing pattern of sanitary sewerage facilities. This theory says that such a payment method did prevail when combined sewers carrying both sanitary sewage and storm waters were more common and were financed from the general property tax. Under present circumstances it is argued that storm water is merely another form of liquid waste and therefore is legitimately financed from the proceeds of sanitary sewerage payments. If this argument is accepted, the same forms of cost apportionment just discussed may be utilized —with the exception of the service charge. That is, a special benefit assessment may be made against particularly benefited property, and also that portion of the costs attributable to the

general benefit of the community may be met from general taxation. A direct relationship between the extent of use of the sanitary sewer and the storm sewer is difficult to establish. One suggestion is that the regular sanitary sewer service charge might be increased uniformly throughout the community on the principle of a minimum charge to cover maintenance and some capital costs of the storm sewers. In this manner the costs of storm sewers would be brought within the regular sanitary sewerage facilities future budget. Since this problem affects chiefly new areas, caution must be exercised to prevent older areas from being assigned an undue share of the burden of new storm sewer construction.

Combined Waterworks and Sewerage Facilities Organization

Several states now permit combination of the waterworks and sewerage facilities operations for management and financing purposes. Some traditional patterns, no doubt, are upset by this method, and there can be suspicion that expediency may be the motivating factor in some instances, for waterworks have a longer record of profitable operation than have sewerage facilities. On the other hand, as the courts have pointed out in approving such operational mergers, the close relationship between an adequate safe water supply and distribution system and the proper disposal and treatment of sewage indicates that the two systems may logically be regarded as coequals in importance and necessity. Little specific information is available concerning the financial benefits of this form of organization, but it is validly expected that bond issues supported by the revenues of combined systems would be more attractive than either alone. Furthermore, the authority of the municipality to discontinue the water supply due to delinquent bills for sewer service would enhance collectibility of this charge. This unified form of operation would not change the basis of payment for either water or sewerage service, however. Any savings incurred would arise from reductions in management, purchasing, labor, and other similar costs.

Other Possible Sewage Practices

In passing, comment can be made on recent reports of firms offering to provide for sewage collection and treatment in small communities on a private business basis. Perhaps such a solution is feasible, but little experience exists at present to make a definitive judgment.

Community sales of sewage effluent to industrial users should not be overlooked as a revenue source, and it appears certain that this form of endeavor will grow. The price at which effluent can be sold depends on the cost to industry of obtaining water of like quantity and quality from alternate sources. Where no alternate source exists, the determination of a selling price by the municipal officials will be governed by evaluation of the well-being of the community and by estimation of the value to industry in terms of meeting competitive conditions for the industrial product.

Summary

In conclusion, it can be said that the community apportionment of the cost of sewerage facilities among its members is of growing importance because of the magnitude of these costs, and because of the necessity for an equitable system to meet the standards of justice requisite in a democracy. The use of the service charge in conjunction with special benefit assessments and general taxation allows the closest approximation to complete equitableness that can be attained, for the use of these measures permits consideration of both concepts—benefits and use. Furthermore, this system enables the taxpayer to visualize more accurately the scope of this particular activity for which he bears the cost.

APPLICATION OF MOLECULAR FILTER TECHNIQUES TO THE BACTERIAL ASSAY OF SEWAGE*

II. EXPERIMENTAL RESULTS FOR SETTLED SEWAGE

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In the first paper of this series, Goetz (1) proposed two techniques for the bacterial assay of sewage or heavily contaminated water by means of molecular filter membranes. These techniques differ from those commonly employed in the analysis of drinking water, owing to the high bacterial density in sewage and the rapid clogging of pores by suspended and colloidal solids. The first and most obvious procedure involves serial dilutions and variable sample sizes to achieve maximum range of density with a minimum number of filtrations. The second method employs a concentrometric filtration by means of special apparatus not yet available commercially.

It is the intent of part two of this series to describe experimental data from the bacterial assay of domestic sewage that is untreated other than by plain sedimentation. The results of molecular filter techniques using serial dilutions and variable sample sizes are compared with those from conventional MPN procedures.

Sewage Characteristics

For all of the experimental work described in this paper, sewage from the Pasadena, Calif., metropolitan area was used. Samples were taken from the trunk sewer of the Los Angeles (Calif.) County Sanitation Districts near the site of the abandoned Tri-Cities Sewage Treatment Plant. This trunk sewer serves Pasadena, San Marino, South Pasadena, and parts of contiguous communities, with a total sewered population of about 200,000. The sewage is representative of typical domestic drainage with very little industrial waste and no ground-water infiltration. Moreover, no storm-water run-off was included in any of the samples used for these experiments. Velocities in trunk and lateral sewers are high, and consequently the sewage is quite fresh at the point of collection. To assure an approximate degree of uniformity, the samples were always taken on a week day at about 9 AM.

Consideration was also given to the use of a synthetic sewage inoculated with cultured coliform organisms. Such a sewage would have the advantage of uniformity from test to test, and would eliminate the need for sampling and transportation of natural sewage. It would not, however, be strictly comparable with natural sewage in the variety of organic substances, the size distribution of suspended and colloidal solids, or the multiplicity of organisms that might be antibiotic or symbiotic to coliform bacteria.

By standardizing the time, place, and conditions of sampling, it was possible to get natural domestic sewage of reasonably constant characteristics. The normal ranges of solids, pH, BOD, and other analyses for raw sewage are shown in Table I. Concentrations are expressed as milligrams per liter (mg/l).

The raw sewage was brought to the laboratory promptly and poured into a

* Presented at the 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

TABLE I.—Typical Composition of Raw Sewage *

Analysis	Normal Range
Total solids (mg/l):	
Total	1,100 –1,300
Fixed	450 – 550
Volatile	650 – 750
Suspended solids (mg/l):	
Total	350 – 600
Fixed	50 – 150
Volatile	300 – 500
Dissolved solids (mg/l):	
Total	600 – 800
Fixed	350 – 450
Volatile	250 – 400
Settleable solids (mg/l)	15 – 30
pH	7.4 – 8.4
BOD (20° C):	
5-Day (mg/l)	175 – 250
Reaction velocity, k_1, per day	0.15– 0.18
Alkalinity, as $CaCO_3$ (mg/l)	300 – 400
Ammonia, as nitrogen (mg/l)	15 – 30
Organic nitrogen (mg/l)	18 – 28

* Sampled from main trunk sewer between 8 AM and 10 AM.

large ceramic crock. It was allowed to settle quiescently for a time and to a depth corresponding to a surface overflow rate of 400 gpd/sq ft. Then the upper portion was removed by siphoning and analyzed promptly. Partial analyses of this settled sewage on the dates when it was used are shown in Table II.

A foremost asset of settled Pasadena sewage, as a medium for bacterial experimentation, is its relatively uniform density of coliform organisms. Usually this parameter may be expected to vary widely in grab samples of sewage taken over a period of 18 months. Yet, by standardizing the time and conditions of sampling and by the selection of a trunk sewer draining a large municipal area without infiltration or major industrial wastes, it was possible to obtain sewage of remarkably uniform coliform content. As shown in Table II, the confirmed MPN values in 50 tests ranged from 6,000,000 to 240,000,000 per 100 ml, with a median value of 40,000,000 per ml. With the molecular filter technique, the results of 60 tests varied from 7,000,000 to 254,000,000 per 100 ml with a median value of 44,000,000 per 100 ml.

By way of comparison, it is interesting to note that La Cava (2) found the MPN values of raw sewage at Laconia, N. H., to vary from 1,500,000 to 75,000,000 per 100 ml (except for one abnormally high value) with a median of 15,000,000 per 100 ml. His tests were conducted in January and February 1953. Despite precautions to minimize surface run-off, there is no question that the sewage in Laconia was diluted by ground-water infiltration, because the suspended solids and BOD values were correspondingly lower than those for Pasadena sewage. The general order of magnitude of coliform concentrations, however, is not significantly different in the two instances.

To the casual observer, the spread and variability of bacterial data may give an impression of inaccuracy and unreliability. Much of this variability, however, is due to the heterogeneous and changing nature of sewage; and some of it is attributable to the nature of the test.

Any small sample from a large heterogeneous liquid is subject to chance and governed by the laws of random sampling. Multiple samples from the same liquid might be expected to yield different results. This effect is especially evident when the liquid contains suspended solids. Normally, the sample is withdrawn in a 1-ml pipette with a small opening that excludes larger particles. This sample may be placed in 99 ml of dilution water. Despite thorough shaking, the diluted sample will not be homogeneous. Hence, when a subsequent sample is withdrawn for testing or for further dilution, the laws of random sampling come into play again. When repeated for several dilution steps, the probabilities of obtaining an exact representative sample are greatly reduced. Yet, the results are meaningful when inter-

preted properly as orders of magnitude and as indicators of trends and effects.

Techniques of Bacterial Analysis

The molecular filter procedures used in these experiments were similar to those described by Goetz (1) and by an American Water Works Association task group report (3). Dehydrated scheduled nutrient pads[1] (DSN) were employed for all coliform tests. These pads and accompanying membranes were received in sterile packages of six units each. The DSN pads contained two elements: an upper leaf impregnated with a stimulating general nutrient, and a lower leaf impregnated with an Endo-type inhibitory nutrient (without brilliant-green additive). As demonstrated by Eye *et al.* (4) the DSN pads provide excellent sheen colonies and maximum inhibitory action against extraneous organisms.

Samples of settled sewage were pi-

[1] Commercially available under the trade name "Isopor."

TABLE II.—Partial Analyses of Settled Sewage

Date	Temp.* (° C)	pH	Suspended Solids† (mg/l)	Coliform Concentration† (10^6 per 100 ml)		
				Confirmed MPN	Membrane Filter Count	
					Higher Dilution	Lower Dilution
1954						
Sept. 13	24.5	7.4	191	—	—	58
16	25	7.6	215	—	300‡	254
21	25	8.2	162	—	20‡	7
23	24	7.5	180	—	12	19§
Oct. 11	22.5	8.1	160	—	30	23§
8	25	8.0	137	—	22	22§
15	28	7.9	190	—	48	24§
22	23.5	—	150	—	42	26§
29	22	8.1	109	—	36	32§
Nov. 12	23	—	98	—	22	18§
19	24.5	8.2	112	—	30	20§
26	22	7.9	238	—	—	—
Dec. 3	20.5	8.2	110	62	44	24§
10	21.5	8.0	134	23	24	22
17	22	8.6	162	6	12‡	34
20	23.5	8.2	165	50	56	24
1955						
Jan. 27	19	8.4	104	62	52	32§
Feb. 4	15	8.2	106	62	76	16§
11	19	8.3	157	62	20	18
18	20.5	8.2	118	23	36	20
25	21	7.9	120	23	12‡	18
Mar. 11	20.5	7.9	104	12	44	24§
21	22.5	—	128	62	104	27§
22	20	7.6	120	62	80	20
28	25	7.8	177	62	200‡	36
Apr. 1	24	7.7	127	62	124	25§
4	—	7.6	144	70	—	60
11	—	7.6	132	62	—	34
18	—	7.3	109	62	80‡	46
25	20.0	—	144	—	—	—

* Temperature taken at time of test, not at time of sampling.
† After settling in a crock for a time and depth corresponding to 400 gpd/sq ft.
‡ Discarded, because of less than five colonies on membrane.
§ Discarded, because of over 50 colonies on membrane.

TABLE II.—Partial Analyses of Settled Sewage (*Continued*)

Date	Temp.* (° C)	pH	Suspended Solids† (mg/l)	Coliform Concentration† (10^6 per 100 ml)		
				Confirmed MPN	Membrane Filter Count	
					Higher Dilution	Lower Dilution
May 2	20	7.8	130	62	102	28
9	21	7.3	125	—	—	—
16	22.5	7.5	152	240	140	48§
23	20	7.8	117	62	20‡	14
June 15	21	7.8	90	62	100	56
21	23	7.6	108	62	20‡	24
27	21	7.9	126	23	60‡	32
29	21	8.0	85	23	60‡	20
July 5	22	7.8	149	130	60‡	50
11	23	7.8	140	23	60‡	42
13	24	—	92	23	20‡	—
19	26	7.8	90	23	20‡	50
25	25	8.0	150	23	20‡	44
26	—	—	103	23	20‡	70
Aug. 3	26	7.9	121	23	100‡	76
15	26	7.4	155	23	20‡	50
22	25	7.6	132	13	20‡	46
23	26	7.5	141	23	—	68
30	27	7.2	135	23	40‡	58
Sept. 13	29	7.2	159	23	80‡	98
28	25	7.6	126	62	60‡	94
Oct. 5	24	7.6	140	240	60‡	52
12	23	7.4	164	240	120	140§
26	24	7.9	123	29	20‡	58
Nov. 2	21	8.3	100	62	40‡	34
9	24	8.0	—	62	40‡	52
16	20	7.4	—	23	—	42
30	22	8.0	—	62	—	70
Dec. 19 1956	17	7.7	119	62	80‡	24
Jan. 7	20	8.1	—	23	80	12
28	19	7.4	134	23	—	36
Mar. 16	20	7.9	122	23	40‡	28
21	19	8.0	144	23	40‡	22
24	20	8.2	124	62	80‡	68

* Temperature taken at time of test, not at time of sampling.

† After settling in a crock for a time and depth corresponding to 400 gpd/sq ft.

‡ Discarded, because of less then five colonies on membrane.

§ Discarded, because of over 50 colonies on membrane.

petted into bottles of sterile dilution water, shaken thoroughly, and further diluted in series to concentrations of 10^{-5}, 10^{-6}, and 10^{-7}. Standard BOD dilution water, as described in "Standard Methods" (5), was used for all dilutions in order to avoid any osmotic effects that might arise with distilled dilution water. Portions of 10 to 100 ml of the suitable dilution were then passed through a membrane by means of recommended sterile procedures (3) (5). Meanwhile, the nutrient pad was placed in a sterile 60-mm petri dish and rehydrated with 2.3 ml of sterile distilled water. Following filtration, the membrane was laid carefully on the wet nutrient pad to avoid air traps;

then the dish was wrapped in parafilm, inverted and placed in a 35°C incubator.

The coliform organisms trapped on the membrane developed overnight (about 18 hr) into readily discernible and distinguishable colonies with a green metallic sheen, provided that they were not too numerous. The non-sheen colonies were generally absent or at least insignificant in number and size. When a membrane contained more than 50 sheen colonies, a coalescence or interference of colonies was suspected. For this reason, all tests were conducted with two or more dilutions so that one membrane would show at least 5 (for statistical reliability) and preferably less than 50 sheen colonies.

Replicate tests and the data in Table II showed that the coliform concentration was generally higher when computed on the basis of a lower count on the membrane. Thus, 50 ml of a dilution of 10^{-5} might produce 140 colonies while 50 ml of a dilution of 10^{-6} of the same sample would show 22 colonies. For this example, the computed concentration of 44×10^6 per 100 ml for the higher dilution was considered to be more reliable than 28×10^6 per 100 ml for the lower dilution. In Table II, results based on less than 5 or more than 50 colonies were discarded as shown. Where both counts fell within these arbitrary limits, the results of the higher dilution were used.

The MPN analyses were performed in accordance with "Standard Methods" (5) using serial dilutions and duplicate tubes of lactose broth as the presumptive medium. Lauryl-tryptose-broth fermentation tubes could have been used for this stage of the analyses, thereby eliminating many of the confirmed tests, especially following chemical disinfection. It was felt desirable, however, to use the straight lactose method in order to assess the concentration of spore formers and to note the effect of disinfection on their numbers in a subsequent part of this work.

Eosin-methylene-blue (EMB) agar was selected as the confirmatory medium in order that a visual inspection of the colonies might indicate whether the transferred organisms were definitely fecal or perhaps of soil origin. This appearance did not affect the results in this report, for growth of any nature on the EMB plate was considered to be a positive test for coliforms. Bacterial assay was conducted routinely through the confirmed test, but not the completed test, which is seldom used in sewage work (5). In the few completed tests checked during this experimentation, the confirmed tests always showed positive completion.

Experimental Results

The applicability of the molecular filter technique for the bacterial assay of raw settled sewage can be demonstrated by a statistical analysis and comparison of the data presented in Table II. For the 50 tests when membrane filter and MPN results were both available, the data were arrayed and grouped for plotting, after which the parameters of geometric normality were determined in accordance with procedures described by Thomas (6). For the membrane results, the geometric mean (and median) value was found to be 46×10^6 per 100 ml; the geometric standard deviation was 1.81, as shown by Figure 1; and the arithmetic mean computed from geometric parameters was 55×10^6 per 100 ml. By way of comparison, the 50 concurrent MPN results were analyzed similarly, as shown in Figure 2. Here the geometric mean was 40×10^6 per 100 ml, the geometric standard deviation was 2.25, and the arithmetic mean computed from geometric parameters was 55.5×10^6 per 100 ml. Thus, the MPN and membrane results appear at first glance to be in remarkable agreement.

Unfortunately, however, there is a statistical bias in the MPN test, as

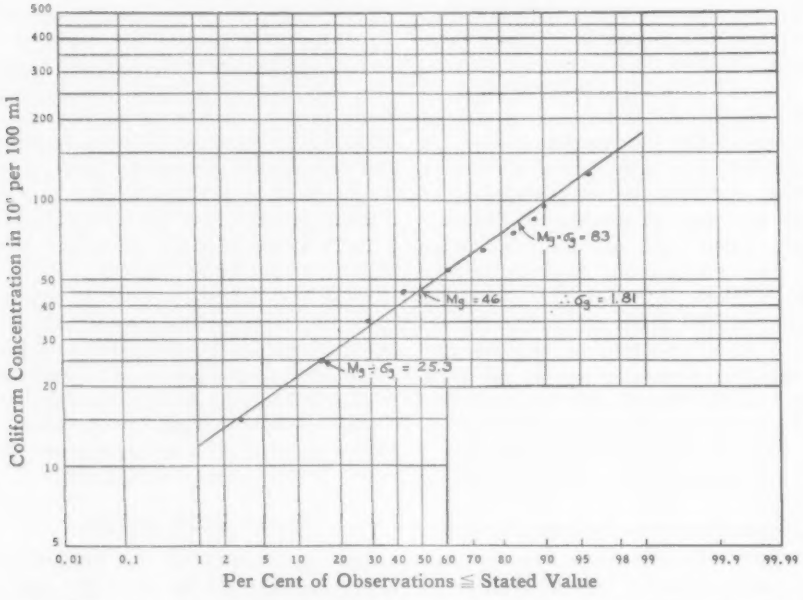

FIGURE 1.—Analysis of molecular filter membrane data for settled sewage samples, 50 tests.

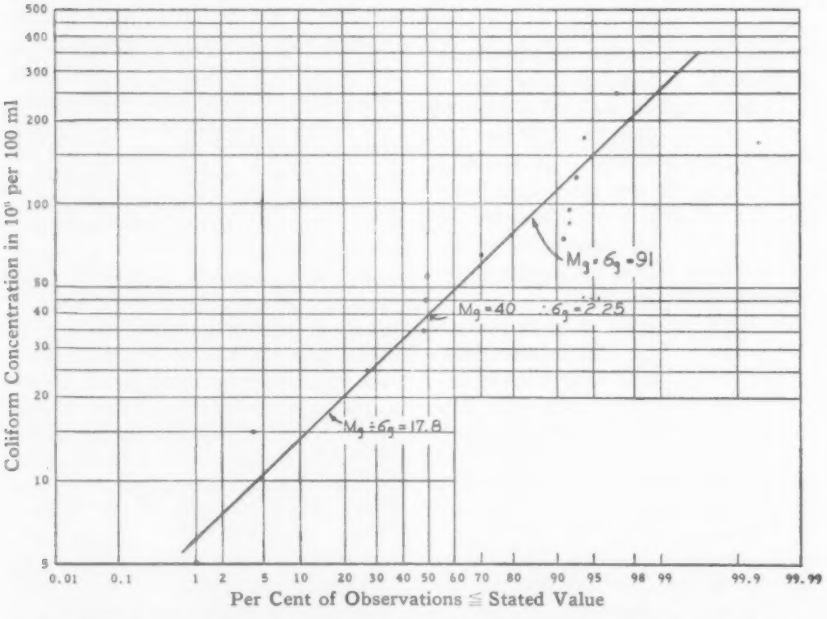

FIGURE 2.—Analysis of MPN data for settled sewage samples, 50 observations.

noted by Thomas (6). This bias is a function of the number of fermentation tubes used in each dilution, thus

$$c = e^{-0.805/n}$$

In which n represents the number of tubes and c is a correction factor. For the two-tube analyses on which these MPN values were based, a correction factor of 0.669 is indicated. This correction makes the geometric and arithmetic MPN values slightly lower than the corresponding membrane filter parameters, but the agreement is still good.

Another comparison of the same MPN and membrane filter results for settled sewage is shown by Figure 3. The scattering of plotted points above and below the 45-deg lines indicates that membrane results are likely to be both higher and lower than MPN data for concurrent samples. The two-tube MPN values tend to be either 23×10^6 or 62×10^6 per 100 ml, owing to the operation of this statistical yardstick.

For the 21 instances when the recorded MPN was 62×10^6 per 100 ml, the membrane values ranged from 14×10^6 to 124×10^6 per 100 ml, with a geometric mean value of 46.7×10^6 per 100 ml. Corrected for its bias, the corresponding true MPN was 41.5×10^6 per 100 ml, or quite close to the geometric

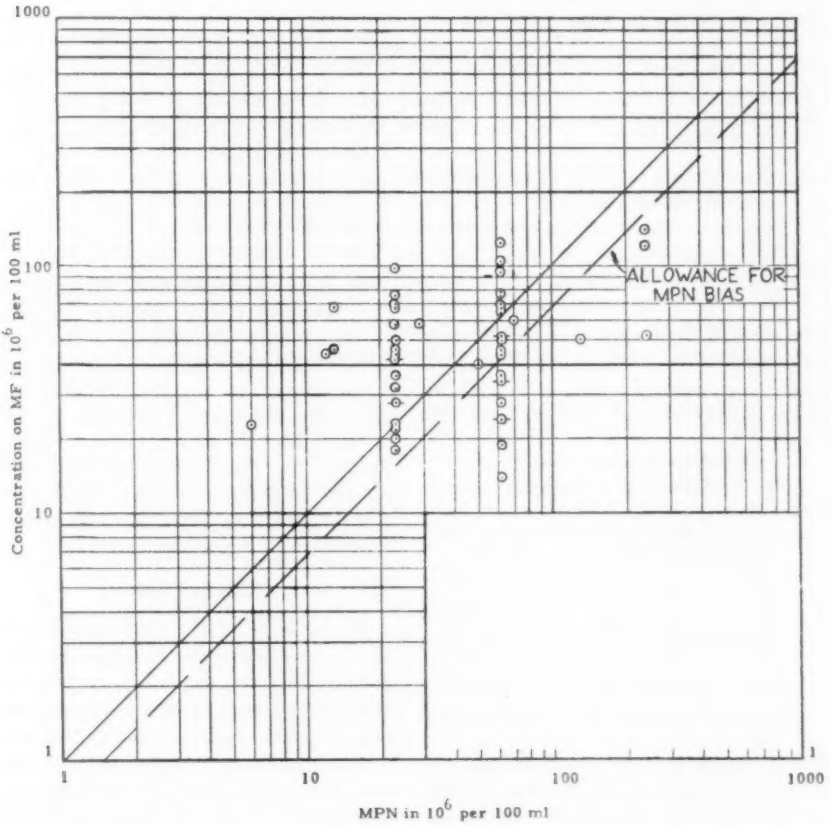

FIGURE 3.—Comparisons of molecular filter membrane and MPN concentrations in settled sewage, 50 observations.

mean membrane value. For the 19 instances when the recorded MPN was 23×10^6 per 100 ml, the membrane results varied from 18×10^6 to 98×10^6 per 100 ml with a geometric mean of 40.2×10^6 per 100 ml. The corresponding unbiased MPN was 15.4×10^6 per 100 ml.

One may reasonably inquire, "Is the two-tube MPN test a fair match for the molecular filter membrane procedure? Would it not be better to use five-tube tests where the bias is reduced and the statistical reliability is improved?" To answer those questions, multiple tests were conducted on a sample of sewage by both techniques using 10^{-5}, 10^{-6}, and 10^{-7} dilution. The confirmed MPN results were as follows:

Item	Test		
Dilution used	10^{-5}	10^{-6}	10^{-7}
Size of diluted sample (ml)	1	1	1
Number of inoculated tubes	5	5	5
Number of positive confirmed tubes:			
Test A	4	4	0
Test B	5	1	0
Test C	5	2	0
Test D	5	0	0

For each of these tests, the MPN values as recorded in "Standard Methods" and as corrected for bias ($c = 0.85$ for a five-tube test) are given in Table III.

TABLE III.—MPN Data for Tests A, B, C, and D

Test	Recorded MPN per 100 ml	Corrected MPN per 100 ml
A	34×10^6	28.9×10^6
B	33×10^6	28.0×10^6
C	49×10^6	41.6×10^6
D	23×10^6	19.5×10^6
Means	34.5×10^6	29.3×10^6

Using the membrane technique, the results of five tests with the same diluted samples used in the MPN determinations were as follows:

Item	Test		
Dilution	10^{-5}	10^{-6}	10^{-7}
Size of diluted sample filtered (ml)	50	50	50
Number of sheen colonies per membrane:			
Test A	80	16	1
Test B	120	11	1
Test C	124	18	1
Test D	111	16	0
Test E	123	16	2

Table IV gives the calculated concentrations for the membrane in the five tests.

TABLE IV.—Calculated Concentrations for the Membrane

Test	Dilution		
	10^{-5}	10^{-6}	10^{-7}
A	16×10^6	32×10^6	20×10^6
B	24×10^6	22×10^6	20×10^6
C	25×10^6	36×10^6	20×10^6
D	22×10^6	32×10^6	—
E	25×10^6	32×10^6	40×10^6
Means	22.5×10^6	30.8×10^6	25×10^6

In these membrane tests, dilutions of 10^{-7} gave numbers of colonies too few to count with significance. Between the 10^{-6} and 10^{-5} dilution, the former is considered to be more reliable because the numbers of colonies lie between 5 and 50, as explained. Consequently, the mean value of 30.8×10^6 per 100 ml is deemed best for the membrane tests. This value checks the corrected mean MPN almost perfectly.

Conclusions

On the basis of the data obtained in these investigations, it appears that molecular filter membrane techniques with dehydrated scheduled nutrient pads (Endo) are applicable to the bacterial assay of raw settled sewage and that the results obtained thereby are comparable to those from confirmed MPN procedures. To assure optimum

results, it is recommended that multiple dilutions be examined so that the number of sheen colonies on one or more membrane filters will be between 5 and 50.

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SANITARY ENGINEERING EDUCATIONAL MATERIAL

The Public Health Service has announced the availability by April 1 of two outstanding contributions aimed at the attraction of students to a career in sanitary engineering.

The first is a film, titled "Engineering Your Health," in sound and color and 13.5 minutes duration. This is a commercially produced film and is the first and only film devoted to sanitary engineering as a desirable professional career. It is aimed specifically at the freshman and sophomore collegiate group of students who are science-minded and even thinking about engineering. The film should be equally attractive and interesting to alert high school students of the 11th and 12th grades. It is incentive-motivation oriented rather than instructional or how-to-do-it oriented.

Accompanying each reel will be a question-and-answer brochure. This booklet has been prepared so that an adult, who may not be a sanitary engineer, can brief himself or herself and then show the film within the larger framework of a serious discussion of occupational choice. This means that a science teacher, a vocational guidance specialist, an interested M. D. or lay member of the public health department, or other interested person could lead such a discussion. The film may be borrowed, rent-free, from DHEW Regional Offices or from Public Inquiries, Public Health Service, Washington 25, D. C.

The second item, available by March 15, is the first comprehensive vocational guidance brochure devoted exclusively to sanitary engineering. It is titled "Toward A Healthier World: Your Career in Sanitary Engineering." It will be multi-colored, interestingly illustrated, and about 16 to 20 pages long, and is written in simple, direct language for interested secondary school students. Copies may be secured either from the DHEW Regional Offices or Public Inquiries, Public Health Service, Washington 25, D. C.

CONTINUOUS SAMPLING OF TRICKLING FILTER POPULATIONS

II. POPULATIONS

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Reports relative to sewage treatment contain few observations regarding the study of organisms inhabiting trickling filters. Available information pertinent to fungi in this habitat has been reviewed recently by Cooke (1)(2). The most important contributions to the knowledge of fungus populations have come from England (3). Work in the United States has been restricted to studies of organisms which may have deleterious effects on the operation of filters (1), or to the commonest or most unusual species found on trickling filters in the treatment of industrial wastes (4). Becker and Shaw found little or no fungus material in scrapings from filter stone on beds at Pullman, Wash., and Moscow, Idaho, and concluded that fungi were not of importance. The information on algal populations is even more scanty as a survey of the series of papers by Stanbridge (5) shows.

Several species of fungi have been listed as occurring in the trickling filter population. These include: *Fusarium aquaeductuum, Sepedonium* sp., *Ascoidea rubescens, Subbaromyces splendens, Geotrichum* (usually listed as *Oidium* or *Oospora lactis*), *Oospora fragrans, Penicillium* sp., *Dictyuchus* sp., *Pythium* sp., and *Sporotrichum* sp. This list is based primarily on work done in England, New York, and New Jersey. Other studies on the biota of trickling filter slimes have not tried to identify "fungi" according to species. Various workers listing fungi occurring in filter slimes implied that a number of species may have been present.

Publications on the biology of trickling or percolating filters mentioned *Chlorella, Stigeoclonium, Euglena, Phormidium,* and *Oscillatoria* among the algae found in this habitat. In such publications no critical evaluation has been made concerning the species present. It was implied that other algae associated with polluted habitats occurred in trickling filters. Some of the problems in the study of such organisms have been discussed in relation to the study of bottom algae in streams.

Difficulties in evaluating numbers of bottom algae have been pointed out by Lund (6) who stated:

> There are, moreover, a number of factors mitigating against the accuracy and value of the counting method, particularly as applied to these types of flora. Thus the occurrence of some of the bottom-living algae in clumps or their movement into certain restricted temporarily favorable areas renders large-scale counting necessary to obtain correct numerical estimations.

Lund indicated that it was impossible to obtain counts large enough to achieve a degree of accuracy from the standpoint of time. A method was used which he recognized as inadequate but which was maintained for uniform results. In a preliminary survey of unknown habitats, he considered it of greater importance to obtain a general idea of the various types of communities and their variations, than to make single detailed observations.

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Usinger and Needham (7) cited a verbal communication by Margalef in which he stated that a comparative study of algae on glass slides and on the natural rocks in streams, indicated that only special kinds of algae attach to glass and that samples taken in this way are comparable neither in quality nor in quantity to samples taken under natural conditions.

Brooks (8) set up laboratory cultures in large glass vessels containing samples of surface sand and algae taken respectively from a newly cleaned sand-bed and from a bed that had been in operation for 9 weeks. Glass slides were placed on the sand and in the vessels, and weekly counts were made of the numbers of algae which settled on them, including both epiphytic and bottom-living forms. The counts showed that after a time the unattached algae disappeared from the slides in both vessels, although at first they appeared to grow well. Epiphytic forms such as *Achnanthes*, *Ulvella*, and *Chaetopeltis*, on the other hand, continued to thrive.

Blum (9) placed sterilized rocks in unpolluted riffles of the Saline River in Michigan. Colonization by the diatoms *Diatoma vulgare* and *Gomphonema olivaceum* was so rapid that colonies became visible to the naked eye within 10 days. Colonization by *Diatoma* started October 27, and by *Gomphonema* about November 25. Colonization of *Gomphonema* ceased by April 10, indicating a seasonal capacity to colonize bare areas. It was concluded that both algae were capable of colonizing new areas at any time throughout their periods of growth and dominance.

General Populations

Each of the 20 filters at the Dayton, Ohio, sewage treatment plant supports a separate community or biocoenose of macro- and micro-organisms. Each of these biocoenoses is independent of the other, except for a common source of inoculum and food materials. Filter sloughings, which become filter sludge, are settled out of the filter effluent in the final settling basin and returned to the preaeration chambers.

In starting a new filter, an inoculum from another filter may be used, or may be supplied from the settled sewage and the air. The length of time required for building up the biological film to an optimum association of organisms is uncertain. However, the length of time required for this association to effect an adequate removal of BOD, the index of efficiency of the filter, is known in many instances according to Gilcreas and Sanderson (10). While it may take only 50 days for the appearance of the population characteristic of a mature filter, this does not indicate that the population has reached a stable state in regard to all the conditions of its environment, both internal and external.

The surface film on the filters under consideration reached a maximum thickness of 2 to 3 mm during the 57 weeks of observation. This film was teeming with life of many types. It was continually irrigated by spray from the nozzles of the rotary distributor. If the arms came to a stop or were slowed, the surface film dried and flaked off later with the rush of new flow, becoming part of the filter bed effluent.

The community of organisms comprising this film is built up without interference or disturbance from man, except for the manual removal of undesirable elements, such as mosses which may grow around the edge of the filter (11), flushing or drowning for control of the insect larvae whose adult stages become nuisances, or for major shutdowns.

The community of organisms on any one filter is made up of many types of microorganisms and a few macroscopic species. These include colonies and filaments of bacteria, colonies of yeasts, filaments of fungi, and colonies and

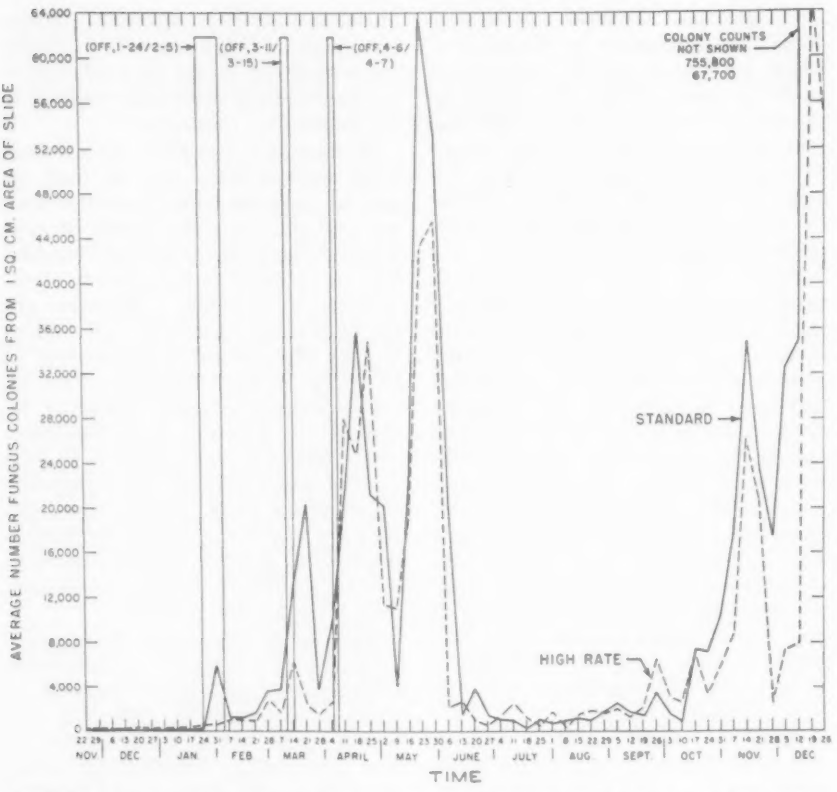

FIGURE 1.—Average number of fungus colonies obtained from 1 sq cm of slide surface throughout the period of the study.

filaments of algae. Moving about through the complex community are a number of kinds of protozoans (of which some may be stalked and thus sessile-attached), and nematodes. The larvae of several types of insects, as well as worms and snails which feed on the slime, complete the population.

Fungi

In the filter beds, the slime on the stones is formed by several phases of the complex community, depending on the depth of the filter. Only the surface phase has been examined in this study. The average number of fungus colonies observed per square centimeter of slide surface is shown in Figure 1. Below the first foot of filter depth, where light does not penetrate but where aeration is maintained by the spacing of the stone, algae are probably absent or much reduced. The filter is aerobic with the possible exception of small areas which may become septic as excessive growth clogs the spaces between the stones. However, it is thought by some that septicity may develop at the base of the film, especially on the under side of the stones, and may contribute to the sloughing process

The populations of fungi are usually as invisible on casual observation as the bacteria and yeasts. When seasonal conditions are good, mostly in the

spring, colonies of *Fusarium aquaeductuum* may become obvious through the orange color of their spores. Occasionally the spore color may dominate an entire filter making it appear yellowish, orange, or even burnt umber in color. Throughout the film, the mycelium of filamentous fungi is found attached to the stones. On close observation a layer of fungus filaments can be seen covering the algal cells which intermingle with the fungi.

The standard-rate filter and the high-rate filter each exhibited different dominant series of fungi. On the high-rate filter, these fungi in order of abundance were: *Fusarium aquaeductuum, Geotrichum candidum,* and *Pullularia pullulans;* on the standard-rate filter the dominants included: *Coniothyrium fuckelii, Fusarium aquaeductuum* and *Geotrichum candidum.* Occasionally, in the cooler parts of autumn and spring, and in winter, mats of gray or white fungus materials, appearing to belong to *Leptomitus lac-*

TABLE I.—Occurrence of Fungi on Trickling Filters

Constancy Class	Fungus Species	Per Cent Incidence in 57 Samples							
		Standard-Rate Filter				High-Rate Filter			
		Total	Excess	Bottom	Top	Total	Excess	Bottom	Top
I	*Geotrichum candidum*	93.0	84.2	84.2	77.2	100.0	87.7	91.2	87.7
	White Yeasts	96.5	86.0	93.0	84.2	100.0	91.2	96.5	86.0
	Fusarium aquaeductuum	—	—	—	—	98.3	84.2	82.5	87.7
	Rhodotorula glutinis	91.2	75.4	80.7	68.4	93.0	84.2	82.5	66.7
	Penicillium spp.	98.3	82.5	77.2	70.2	—	—	—	—
	Cladosporium cladosporioides	93.0	75.4	80.7	71.9	—	—	—	—
	Margarinomyces heteromorphum	93.0	71.9	64.9	56.1	—	—	—	—
	Coniothyrium fuckelii	91.2	84.2	73.7	71.9	—	—	—	—
II	*Fusarium aquaeductuum*	89.5	80.7	86.0	66.7	—	—	—	—
	Alternaria tenuis	87.7	64.9	60.0	66.7	—	—	—	—
	Pullularia pullulans	82.5	71.9	64.9	43.9	87.7	71.9	68.4	59.6
	Penicillium spp.	—	—	—	—	89.5	80.7	71.9	66.7
	Margarinomyces heteromorphum	—	—	—	—	87.7	71.9	59.6	59.6
	Cladosporium cladosporioides	—	—	—	—	84.2	61.4	71.9	64.8
III	*Moniliaceae* spp.	70.2	43.9	60.0	49.1	63.2	36.8	54.4	54.4
	Trichoderma viride	66.7	50.9	33.3	21.1	66.7	50.9	43.9	26.3
	Penicillium lilacinum	61.4	42.1	49.1	28.1	68.4	50.9	54.3	38.6
	Alternaria tenuis	—	—	—	—	73.7	45.6	35.1	59.6
	Coniothyrium fuckelii	—	—	—	—	73.7	56.1	42.1	47.4
	Aspergillus niger	—	—	—	—	59.6	26.3	40.4	14.0
	Mucor fragilis	—	—	—	—	56.1	40.4	29.8	12.3
IV	*Mucor fragilis*	42.1	29.8	15.5	3.5	—	—	—	—
	Epicoccum nigrum	42.1	22.8	28.1	21.1	42.1	15.8	15.8	28.1
	Aspergillus niger	36.8	27.3	7.0	8.8	—	—	—	—
	Aspergillus versicolor	36.8	19.3	22.8	13.8	40.4	26.3	26.3	5.3
	Cephalosporium spp.	31.6	26.3	21.1	21.1	35.1	21.1	33.3	21.1
	Aspergillus fumigatus	24.6	17.5	12.3	8.8	29.8	17.5	12.3	8.8
	Penicillium ochro-chloron	22.8	12.3	15.8	13.8	26.3	17.5	17.5	15.8
	Rhizopus spp.	22.8	14.0	5.3	1.8	19.3	7.0	14.0	5.3
	Aspergillus ochraceous	21.1	12.3	7.0	3.5	21.1	12.3	8.8	1.8
	Mucor plumbeus	21.1	10.5	13.8	—	22.8	17.5	14.0	3.5
	Penicillium funiculosum	19.3	14.0	3.5	3.5	24.6	12.3	12.3	7.0
	Penicillium oxalicum	19.3	10.5	7.0	3.5	31.6	14.0	14.0	10.5
	Aspergillus flavus	—	—	—	—	40.4	12.3	24.6	15.8

TABLE II.—Occurrence of Fungi on Trickling Filters, Constancy Class V

Fungus Species	Per Cent Incidence	
	Std.-Rate Total	High-Rate Total
Fusarium oxysporum	12.3	3.5
Paecilomyces varioti	10.5	12.3
Aspergillus candidus	10.5	8.8
Subbaromyces splendens	8.8	15.8
Penicillium expansum	8.8	7.0
Gliocladium roseum	7.0	3.5
Aspergillus flavipes	5.3	14.0
Dematiaceae spp.	3.5	12.3
Monilia sitophila	3.5	12.3
Aspergillus spp.	3.5	10.5
Aspergillus sydowii	3.5	10.5
Penicillium herquei	3.5	7.0
Penicillium purpureogenum	3.5	5.3
Penicillium clavigerum	3.5	3.5
Chaetomium globosum	3.5	1.8
Fusarium spp.	3.5	1.8
Penicillium martensii	3.5	1.8
Stemphyllium consortiale	3.5	1.8
Verticillium lateritium	3.5	1.8
Sporotrichum pruinosum	1.8	5.3
Verticillium spp.	1.8	5.3
Absidia spp.	1.8	1.8
Aspergillus wentii	1.8	1.8
Myrothecium verrucaria	1.8	1.8
Penicillium stipitatum	1.8	1.8
Penicillium variabile	1.8	1.8
Penicillium janthinellum	1.8	—
Penicillium nigricans	1.8	—
Fusarium roseum	1.8	—
Memnoniella echinata	1.8	—
Mucor racemosus	—	10.5
Aspergillus clavatus	—	7.0
Gliomastix convoluta	—	3.5
Penicillium velutinum	—	3.5
Ascodesmis microscopica	—	1.8
Fusarium solani	—	1.8
Penicillium luteum	—	1.8
Stachybotrys atra	—	1.8

teus, occurred in small scattered areas on the high-rate filter.

The fungi (Tables I, II, III, and IV) and algae (Table V) observed in this study are listed in descending order of occurrence on the standard-rate and high-rate filters, according to habitat as found on the slides and frames.

The position of the exposed slides on the frames in the filters was as follows:

1. The top surface of the slides was exposed at all times to the sun or to its radiation effects during cloudy weather, and to direct application of sewage from the rotary distributor nozzles.

2. The bottom surface of the slides was never exposed to direct sunlight or radiation, nor to the direct application of sewage; it was protected from evaporation for longer periods when no sewage was being applied to the filters so it did not dry out as quickly nor as completely as the top surface.

3. Excess material, not necessarily associated directly with the slides, developed on the hardware cloth itself in the form of growth around the wires, growth on the marking tag and nylon string, entrapped sludges, etc.

Excess material, as well as the materials from the top and bottom surfaces of the slides, was examined for fungi but not for algae. A layer of fungal, bacterial, and protozoan growth (apparently no algae in the early stages) covered the top side of the slide and screened the bottom growth from direct insolation.

The composition of the community on the trickling filters under study can be described best in terms of the ecological concepts of fidelity, constancy, and dominance. The three ecological terms may be defined as follows:

1. Fidelity—is the degree to which a species is confined to a community or association.

2. Constancy—for the purpose of this discussion, may be defined as the frequency of occurrence in sample areas of uniform size exposed for cumulative regular periods throughout the sampling period.

3. Dominance—is expressed by the estimated total count of colonies of fungi or of cells and clumps of algae per unit or per square centimeter of slide surface. Using the techniques described previously (2), only fungi and algae can be discussed.

TABLE III.—Populations of Trickling Filters

Dominance Class	Fungus Species	Per Cent of Total Colonies							
		Standard-Rate Filter				High-Rate Filter			
		Total	Excess	Bottom	Top	Total	Excess	Bottom	Top
I	*Coniothyrium fuckelii*	39.3	42.1	19.0	62.8	—	—	—	—
	White Yeasts	17.0	15.9	25.7	8.6	27.9	27.1	23.5	16.2
	Geotrichum candidum	14.9	13.3	22.7	3.0	23.1	27.9	21.6	4.2
	Fusarium aquaeductuum	8.6	9.4	7.4	10.7	22.1	18.6	24.8	57.9
	Rhodotorula glutinis	7.9	7.9	8.0	10.3	9.1	8.0	13.0	7.8
	Pullularia pullulans	—	—	—	—	6.7	8.0	6.3	1.9
II	*Cladosporium cladosporioides*	2.7	3.2	4.3	2.4	3.9	4.5	3.7	2.8
	Pullularia pullulans	3.3	3.6	3.9	0.6	—	—	—	—
	Moniliaceae spp.	1.8	1.3	3.3	0.5	1.7	1.7	2.2	1.9
	Penicillium spp.	1.3	1.3	1.6	0.5	1.0	1.2	0.7	1.0
	Margarinomyces heteromorphum	1.0	1.2	0.7	0.7	0.6	0.6	0.6	0.4
	Coniothyrium fuckelii	—	—	—	—	0.9	0.6	1.4	1.9
	Penicillium lilacinum	0.3	0.2	0.6	0.09	0.7	0.6	1.0	0.3
	Alternaria tenuis	0.5	0.5	0.5	0.7	0.5	0.4	0.7	0.5
	Aspergillus fumigatus	0.3	—	0.7	—	—	0.09	—	0.07
	Cephalosporium spp.	0.2	0.1	0.4	—	0.2	—	0.3	0.2
	Trichoderma viride	0.2	1.8	0.3	—	0.2	0.1	0.2	0.1
	Epicoccum nigrum	0.1	0.2	0.1	—	—	—	—	—
	Penicillium funiculosum	0.1	0.1	0.1	—	—	—	—	—
	Penicillium oxalicum	0.1	—	0.2	—	0.1	0.2	0.1	0.2
	Aspergillus versicolor	0.09	0.08	—	—	0.09	0.1	0.1	—
	Aspergillus niger	—	—	—	—	0.2	0.1	—	1.8
	Penicillium ochro-chloron	—	—	—	—	0.2	0.2	0.4	0.1

Since the habitat under discussion is a rather restricted one, in which the organisms present are continually fed with a relatively dilute aqueous nutrient, the fungi react differently than they do in the soil, the habitat with which most of these species are usually associated. In the soil these fungi remain dormant for long periods when no nutrients are available (12). As nutrient-carrying substances such as pieces of leaves, sticks, and similar plant debris become available to the fungus, it develops rapidly, colonizes the new substratum, removes that portion of the material available to its enzyme system, sporulates abundantly, and again becomes quiescent.

In the trickling filter, nutrients are continually available and sporulation is reduced to a minimum in most species. It has been suggested (13) that those fungi which have become adapted to the sewage habitat be considered coprophilous, but this term includes two of the four possible fidelity classes representative of this habitat—lymabionts and lymaphiles. Lymaxenes are present only on occasion and have not become adjusted to the habitat, and lymaphobes are never found in the habitat.

Except where special mention is warranted, data for the three types of habitat on the slides and sampling frames will not be considered separately (Figures 2 and 3). When the slime is observed in place on the surface of the filter rocks, a layer of grey material covering the growth on the stones is apparent (Figure 4). When a stone is picked up, this grey film is broken, revealing the bright green color of the algae underneath. Next to the stones is a thin-to-thick layer made up of fungal, bacterial, and algal material

in and among which the motile algae and protozoans carry on their browsing or scouring. It is suggested that the adherent material on both surfaces of the slides is basically bacterial, fungal, and algal.

On the upper surface, these organisms form an intertwined mass of which some members from each group are attached tightly to the glass. Apparently these slough off partially, but peel off completely only when dry. The whole mass is covered with fungal filaments. On the under surface the organisms adhere to the slide, with fungi and bacteria next to the slide. The fungi do not form a blanket over the algae, reversing the relationship on the rocks. Since the lichen-like layer of material on the rocks, composed of a layer of fungi, a layer of algal cells with intertwined fungus filaments, and a protective layer of fungi, has not been analytically studied as to the relationship of each organism or group of organisms to the whole, little more can be gained from a breakdown of these elements at this time.

The two communities under consideration, one on the high-rate filter, the other on the standard-rate filter, are independent of each other from the point of view of space. Even though the two types of filters are similarly constructed and are fed the same sewage, which is partially recirculated, the

TABLE IV.—Populations of Trickling Filters, Dominance Class III

Fungus Species	Occurrence*	
	Std.-Rate Filter	High-Rate Filter
Absidia spp.	—	√
Aspergillus clavatus	—	√
Aspergillus niger	√	—
Aspergillus flavus	√	√
Aspergillus flavipes	√	√
Aspergillus ochraceous	√	√
Aspergillus sydowii	√	√
Aspergillus candidus	√	√
Aspergillus wentii	√	√
Aspergillus spp.	√	√
Absidia spp.	√	—
Ascodesmis microscopica	—	√
Dematiaceae spp.	√	√
Epicoccum nigrum	—	√
Fusarium spp.	√	√
Fusarium roseum	√	—
Fusarium oxysporum	√	√
Fusarium solani	—	√
Chaetomium globosum	√	—
Gliocladium roseum	—	√
Gliomastix convoluta	—	√
Memnoniella echinata	√	—
Monilia sitophila	√	√
Mucor fragilis	√	√
Mucor plumbeus	√	√
Mucor racemosus	—	√
Myrothecium verrucaria	√	√
Paecilomyces varioti	√	√
Penicillium clavigerum	√	√
Penicillium expansum	√	√
Penicillium funiculosum	—	√
Penicillium ochro-chloron	√	—
Penicillium martensii	√	√
Penicillium variabile	√	√
Penicillium purpureogenum	√	√
Penicillium herquei	√	√
Penicillium stipitatum	√	√
Penicillium nigricans	√	—
Penicillium velutinum	—	√
Penicillium luteum	—	√
Penicillium janthinellum	√	—
Rhizopus spp.	√	√
Sporotrichum pruinosum	√	√
Stachybotrys atra	—	√
Stemphyllium consortiale	√	√
Subbaromyces splendens	√	√
Verticillium spp.	√	√
Verticillium lateritium	√	√

* The per cent of total colonies represented by each species is less than 0.01 per cent in any category.

TABLE V.—Occurrence of Algae on Slides from Trickling Filters

Algae	Per Cent Incidence in 39 Sampling Periods			
	Slide Position			
	High-Rate Filter		Standard-Rate Filter	
	Top	Bottom	Top	Bottom
Green Algae:				
Chlorococcum-type	100.0	100.0	100.0	100.0
Stigeoclonium	61.5	61.5	15.4	46.2
Characium	—	2.5	—	—
Blue-Green Algae:				
Phormidium-Amphithrix	66.7	82.0	74.3	74.3
Pleurocapsa-type	0	0	61.5	35.9
Diatoms:				
Nitzschia palea	61.5	61.5	12.8	38.5

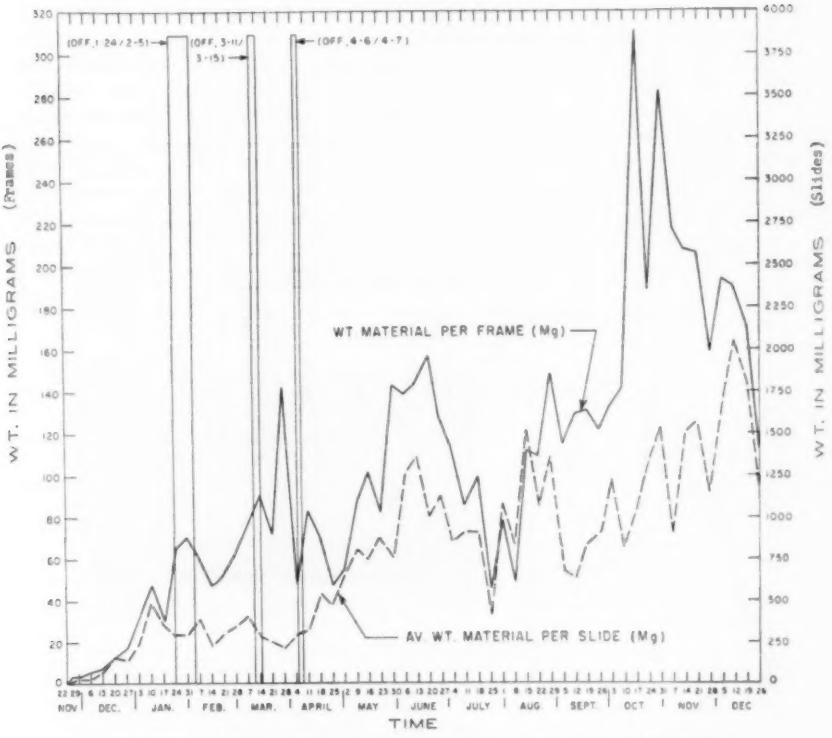

FIGURE 2.—Cumulative growth on the standard-rate trickling filter.

fungi and algae of both populations show a high degree of fidelity throughout the filter fields. From species lists published as a result of sampling other types of plants in New York, New Jersey, Massachusetts, Idaho, and Washington, it may be said that there is a high degree of fidelity between the fungal populations of trickling filters in the United States.

Slides were removed from the stone of a high-rate and a standard-rate trickling filter at weekly intervals for the 57-week period of observation. As a result of the study, five constancy classes can be set up on the basis of per cent of times observed. The species composing each class differ between the two types of filter as will be noted in Tables I and II. If the three sampling areas of each slide are analyzed separately, each will give approximately the same analysis. However, it will be noted that certain species in Classes III and IV are not found as often on the slides as in the excess material. Some others are found more often on the bottom of the slide, and still others on the top.

In tabulating the number of colonies of fungi found on plates poured from blended scrapings from top and bottom slide surfaces and from excess materials, it was found that three dominance classes could be established (Tables III and IV). Between the filters these are more consistent as to species composition than the five constancy classes. The third dominance class includes species represented by less than 0.01 per cent of the total estimated colony count on the slides, al-

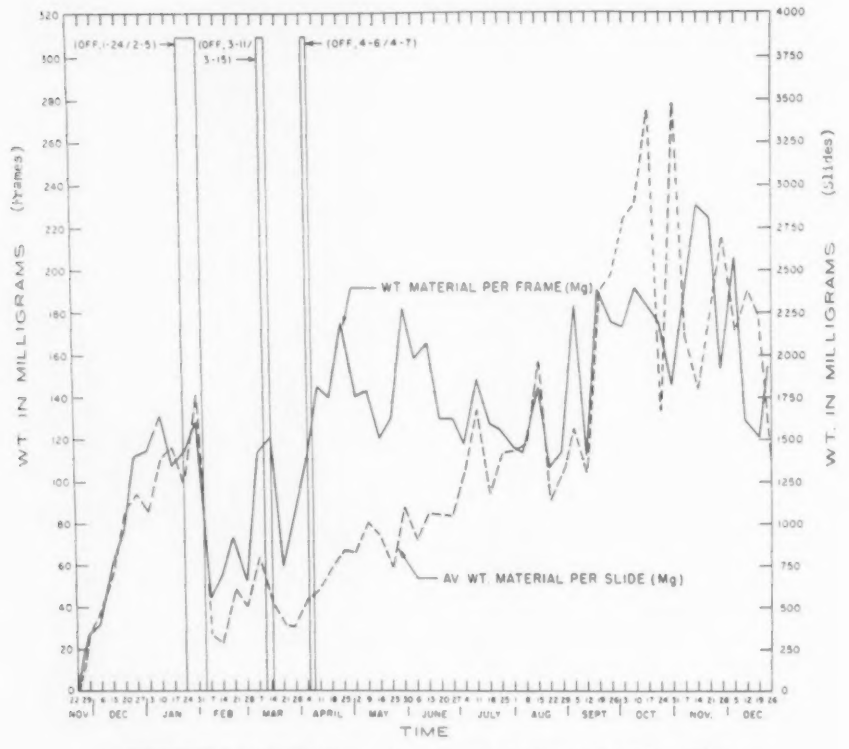

FIGURE 3.—Cumulative growth on the high-rate trickling filter.

though this count may number as many as 150,000 colonies or as few as 12 colonies. Here it is strikingly demonstrated that certain species, such as *Coniothyrium fuckelii* on the standard-rate filter and *Fusarium aquaeductuum* on the high-rate filter, can tolerate the top surface of the slide almost to the exclusion of many other species present on the bottom surface and in the excess materials.

Species in constancy Classes IV and V, and in dominance Class III, include those found only once or twice up to 25 per cent of the time. Most of these species appeared as single colonies on only one of the four plates. Depending on the dilution of the sample used, this colony could be assumed to represent between 12 and 150,000 potential colonies, if the whole sample had been plated. This potential could be interpreted to mean that one colony was present on between 1 and 2,600 sq cm of slide surface. On the other hand, a total of 118,000,000 colonies of *Coniothyrium fuckelii* was recorded on the standard-rate filter exposures of which 19,000,000 colonies were on top and a like number on the bottom.

Different Growth Habit Problems

Several factors must be considered in interpreting the enumeration of fungus colonies obtained from the slides. Bacteria, yeasts, and coccoid algae produce cells in clumps. Such cells are not joined together in filaments, although in some cases cells are so arranged as to appear filamentous and may be enclosed in a mucilaginous sheath. On the other hand, the fila-

mentous fungi and algae have cells which are arranged in filaments and the cells are not generally separable without rupturing the walls. In an aqueous habitat, such as found on trickling filters, most species of filamentous fungi usually do not produce spores, but in some cases atypical sporulation may accompany vegetative growth. In the case of the true yeasts, each vegetative cell may become a reproductive organ in much the same way that bacterial cells will function as propagules as they become dislodged from the colony and are carried by wind and water to new habitats.

Several groups of fungi occur as intermediates between filamentous and yeast-like types. Among these are: (a) *Geotrichum candidum,* whose mycelium undergoes fragmentation, the individual cells becoming spores; (b)

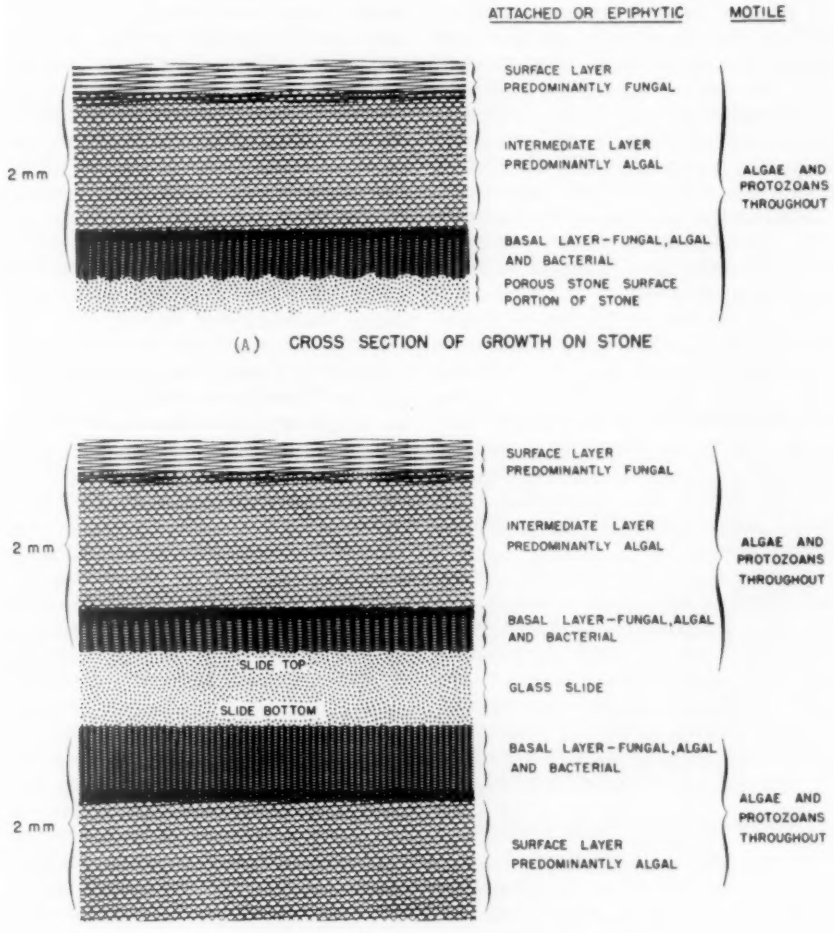
ATTACHED OR EPIPHYTIC
MOTILE
2 mm
SURFACE LAYER PREDOMINANTLY FUNGAL
INTERMEDIATE LAYER PREDOMINANTLY ALGAL
BASAL LAYER - FUNGAL, ALGAL AND BACTERIAL
POROUS STONE SURFACE PORTION OF STONE
ALGAE AND PROTOZOANS THROUGHOUT
(A) CROSS SECTION OF GROWTH ON STONE
2 mm
SURFACE LAYER PREDOMINANTLY FUNGAL
INTERMEDIATE LAYER PREDOMINANTLY ALGAL
BASAL LAYER - FUNGAL, ALGAL AND BACTERIAL
ALGAE AND PROTOZOANS THROUGHOUT
SLIDE TOP
SLIDE BOTTOM
GLASS SLIDE
2 mm
BASAL LAYER - FUNGAL, ALGAL AND BACTERIAL
SURFACE LAYER PREDOMINANTLY ALGAL
ALGAE AND PROTOZOANS THROUGHOUT
(B) CROSS SECTION OF GROWTH ON SLIDE (DIAGRAMMATIC)

FIGURE 4.—Diagrammatic drawing of growth on filter stone (A) and slide (B).

Pullularia pullulans, which produces clusters of yeast-like budded cells or spores on some, if not all, of the cells of its mycelium; and (c) *Margarinomyces heteromorphum,* whose spores may reproduce by budding and on whose mycelium budding may occur. For filamentous stages in the development of these fungi and all other species of filamentous fungi, the blending technique of obtaining satisfactory inoculum for Petri dish cultures gives a certain amount of inaccuracy in final counts. If the mycelial masses were broken up in an ideal manner, each alternate cell of a mycelium should theoretically give a colony and each interposed cell would be killed by the rupturing process. On the other hand, each yeast cell could produce a yeast colony, and in the case of those species which produce mycelium and yeast or yeast-like cells, both types of colonies could be produced.

Because of the possible loss of propagules in the blending procedure and in culturing, it is not expected that the plate counts represent the exact number of fungal cells in the original material. However, when the technique is repeated as exactly as possible, the results should be comparable and should indicate the relative importance of each species.

Because of the abundance of colonies and numbers and types of species obtained, it appears that most species on the filters react favorably to the culture procedure. The correlation between number of colonies and number of occurrences is another evidence that most species present react favorably to the treatment given before plating.

Identification of Fungus Colonies

During the course of this study, colonies which could not be identified on sight or by brief reference to the culture collection and the literature at the time of inventorying the plates were not retained for complete identification. In this way several categories of unknown colonies developed. As compared to other population studies of fungi, these unknown categories are not unusually large and can be expected in any survey study of this type. In some cases it is not profitable to go further with identifications. In the case of the *Moniliaceae* and *Dematiaceae* which were not identified as to species, most such strains have never been induced to fruit (produce identifying characteristics) in pure culture; others have been persuaded to fruit only after long and tedious experimentation with special nutrient media.

The most difficult category with which to work is that of the "white yeasts." Several species belonging to such genera as *Cryptococcus, Candida, Trichosporon,* and *Torulopsis* cannot be identified until after a number of extensive biochemical tests have been completed. The fact that unidentified species of *Penicillium* appear in constancy Classes I and II, and make up 1 to 2 per cent of the estimated total colonies, indicates that a number of species of *Penicillium* exist in this habitat which are not sufficiently distinctive to be recognized at sight and that they occur in insufficient numbers at any one isolation period to have importance.

Several groups, including filamentous fungi as well as yeasts, appear yeast-like on the plates. Until such colonies have been isolated and studied in pure culture it is difficult to make the differentiation between yeasts and molds. *Pullularia pullulans,* the so-called black yeast, is usually white on the primary isolation plates. Sometimes a black colony appears and sometimes a white colony may be ringed with black or have black streaks in it, especially when it is adjacent to other colonies of fungi or yeasts. When a white yeast is colored by the rose bengal dye (a vital stain), or when certain types of rhizobiaceous colonies appear, it is often difficult to distinguish them from the red yeast, *Rhodotorula glu-*

tinis, and other related species without making several pure culture observations. *Fusarium aquaeductuum* usually appears as a moist (rarely dry) orange colony which sometimes has tufts of hyphae arising from the central part of the colony. When the colony color fades to almost white, and the growth is more mucoid than usual, it is difficult to separate this common species from other species which produce yeast-like colonies.

Geotrichum candidum may produce colonies ranging from white mucoid masses to white powdery colonies. These may be variously wrinkled or smooth, large or small, and coremium-like chains of spore-producing hyphae may arise from the colony center. While a spot check under the microscope will suffice to differentiate the various types of colonies mentioned from bacterial colonies because of spore or cell size, colonies of *Geotrichum* can be differentiated readily from other fungus and yeast colonies by the long chains of oblong or barrel-shaped spores which are produced throughout the colony and around its margin.

Fungi Restricted to Filters and Dung

The presence of *Subbaromyces splendens* on all sampling surfaces is of interest. This fungus was first isolated at Pearl River, N. Y., from trickling filter stone near the center of the filter and below the surface layer. It has since been found on trickling filters at Dayton, Ohio, and Pullman, Wash. Because it has not been found elsewhere, it may be considered a trickling filter fungus rather than a sewage fungus in the strict sense of the term. Its imperfect state closely resembles that of the fungus listed from English trickling filters as *Ascoidea rubescens* which has an entirely different ascogenous state and may be more readily cultured.

The nutrition of *Subbaromyces splendens* is poorly understood. The imperfect state appears on rose-bengal and malt agars as fine, cobweb-like hyphae which produce large typical spores. Because of the fine hyphae, this fungus may have been overlooked on some plates and may have been more common on the sampling surfaces than indicated in the tables, although Hesseltine (4) found that it was more common below than on the surface of filters. Its perfect state has been observed only on special media such as lima beans in water agar.

The occurrence of *Ascodesmis microscopica* in one of the samples is also of interest. This fungus has been known previously from only two records, one on tiger dung from Europe, the other on raccoon dog dung from the Bronx Park Zoo, N. Y. Its distribution and occurrence in nature are thus so poorly known that it is impossible to tell what its source could have been at Dayton. There is no way to estimate whether it accompanied pollution from human or animal sources, or whether it came with possible run-off waters entering through household or industrial sewage.

Potential Special Activities of Fungi

In pure culture studies it has been shown (14) that a number of species listed in this paper are able to degrade cellulose to some extent. These species include: *Alternaria tenuis, Aspergillus fumigatus, Chaetomium globosum, Cladosporium cladosporioides, Fusarium oxysporum, Memnoniella echinata, Myrothecium verrucaria, Stachybotrys atra, Stemphyllium consortiale,* and *Trichoderma viride.* Of these, four were common or abundant on the slides, one was found occasionally, the others occurred infrequently. In the studies made to date, there is no indication of the role of these fungi in relation to the large amounts of cellulose (15) present in sewage. It is more likely that cellulose degradation takes place anaerobically in the digesters rather than aerobically on the filters. In this case, these fungi would form only part of the long list of species which can

be referred to as "sugar-fungi," those species capable of using simple carbohydrates rather than complex polymers such as cellulose.

Possible Sources of Filter Populations

In the activities of man, most of the fungi listed are simple contaminants. Many of these species can appear on decaying vegetable materials in the home. *Mucor, Rhizopus, Aspergillus, Penicillium,* and other common genera contain species which cause molds of bread, home-canned goods, and unrefrigerated foods. They could have been introduced to the sewage treatment plant through disposal of spoiled foods.

In the food industry, many food materials are subject to decay by a wide variety of fungi whose spores are introduced during maturation, transit, or storage, and which may be encouraged in their activities under transit or storage conditions. Everyone is familiar with blue molds produced by species of *Penicillium* on apples and citrus fruits. Species of *Alternaria, Rhizopus, Penicillium, Botrytis,* and other fungus genera cause varying degrees of damage to most kinds of fleshy, juicy, and leafy vegetables and fruits. When such damage is noted in the home, in the market, in the warehouse, and even in transit, or on the farm or garden plot, the molded material is discarded.

Some of the fungi in the lists presented here are common contaminants of materials associated with the activities of man in the laboratory, hospitals, and industry. One of the commoner contaminants in the dairy industry, from barn to dairy to home, is *Geotrichum candidum.* It is found in the dust of the barn, as a contaminant of cheese making, and is commonly present in old milk, cream, cottage cheese, and other milk products. Whether or not it comes from these sources through sewage, it is one of the commonest fungi on both types of trickling filters where its white-grey mats may be observed when not filled with dark sludges or obscured by green algae.

Effect of Sloughing

During the course of time on the filter bed, growth may exceed the ability of the substratum to retain it, or excessive washing may remove it mechanically. When the flow to the filter is so low that the growth dries out, portions of it may flake off and these flakes will be removed at the next application of sewage to the bed. This removal of growth contributes to the filter bed sludge which, after settling out in the final settling basin, is pumped to the inlet units. Thus the organisms which grow on the filter bed stones become an additional source of inoculum for the preaeration and filter bed processes. Some of this sloughed growth may be carried in the plant effluent from the final settling basin to the river into which the effluent is drained.

Once a population of organisms has been built up on the stone of the trickling filter it appears to become a permanent part of the treatment plant. The stone of the beds under study was porous slag rock of uneven surface. The size and shape varied from 1 to 3 in. by 1 to 5 in.

The entire population of a single stone never completely sloughs off; an inoculum of fungus, algal, and bacterial material clings to the stone at all times. After severe sloughing this residual inoculum quickly rebuilds the population of the filter.

On the glass slides which were used as sampling devices, more than 100 mg (air-dry weight) of growth per slide appeared on both types of filter before flaking of the film. In flaking, some of the surface of the slide was left bare of any growth, and the slide appeared as shiny as when it was new. If the slide were wet before the flakes were removed, it was difficult to remove all the film, even from areas of this type, with a rubber scraper. Be-

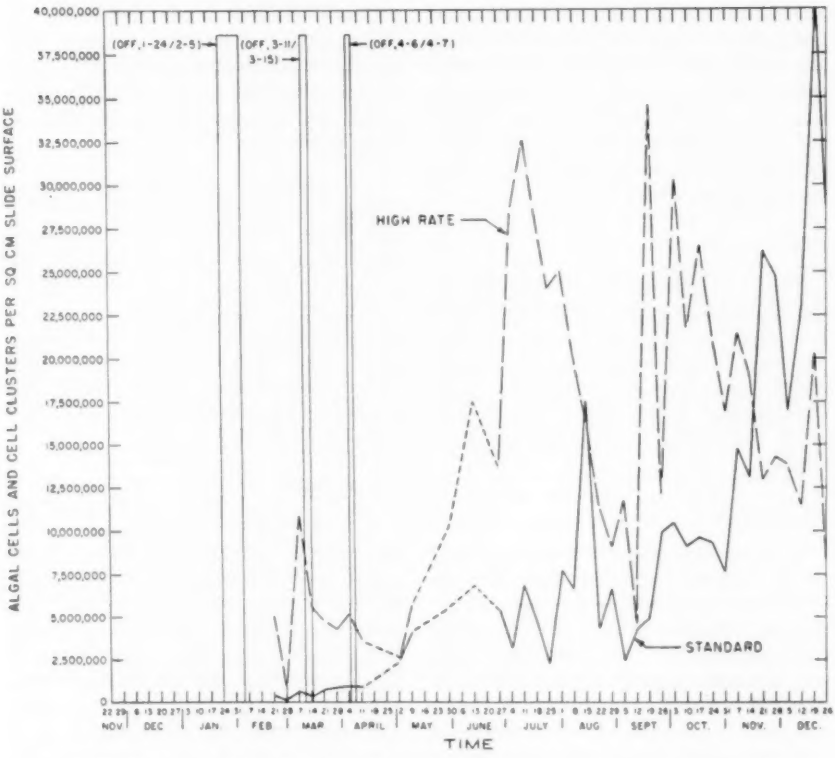

FIGURE 5.—Number of algal cells and cell clusters per square centimeter of slide surface.

fore sufficient growth developed to permit flaking, it was impossible to remove all the growth from the air-dried slide by scraping with a pocket knife or a scalpel, as shown by the production of colonies from slides which had been so scraped and then planted in a Petri dish with 20 ml of agar.

Since the slides constitute a smooth, relatively non-porous surface, it must be assumed that after sloughing or flaking from the filter stone a much larger inoculum remains because of its irregular surface and porosity. Depending on conditions, inoculum of resting cells could be held through periods of quiescence until the occurrence of favorable conditions of growth.

Algae

The numbers of algae were determined by counting a portion of the sample after it had been fragmented in the Waring Blendor. The samples from the tops or bottoms of the four slides in any one series were consolidated and counted in a Palmer nannoplankton slide (16), at a magnification of 430 diameters. The number of fields counted ranged from 15 to 100 depending on the abundance of algae in the sample. The entire slide was then scanned to enumerate species not detected in the field count. Results of the counts are shown in Figure 5.

Throughout the exposure period, stones from both types of filters were

returned to the laboratory several times for study of algae and possible culturing of species. All species enumerated were recorded for both slides and stones so that it may be considered that qualitatively the populations on the slides are typical of those on the filters. The species found were:

Diatoms

The only diatom found growing on the slides was a small and delicate form identified * as *Nitzschia palea* (Kutz.) W. Sm. It was suggested that the material could have been referred to *N. kuetzingiana* Hilse, which is very close to *N. palea* and of which it may be a variety.

Chlorophyta

1. Filamentous species. The two filamentous green algae found growing on the slides were identified † as *Stigeoclonium nanum* Kutz. and *Ulothrix tenuissima* Kutz. The *Ulothrix* could not be separated from the *Stigeoclonium* in counting because of the fragmented condition of the material. However, most of the material observed in the counts was definitely of *Stigeoclonium*. In one case, *Characium* sp. was observed growing attached to this alga.

2. Coccoid species. The coccoid green algae which formed a *Chlorococcum*-like growth on the filters could not be definitely identified, but it is believed to include a palmelloid stage of *Stigeoclonium*. Haensler, *et al.* (17), reported that much of the green algae growing on a trickling filter at Plainfield, N. J., which they called a *Protococcus* stage, was reportedly observed developing into *Stigeoclonium*, but they could not state whether or not all the coccoid cells belonged to the filamentous alga. According to G. W. Prescott, this group included algae identified as *Chlorococcum humicola* (Naeg.) Rab. and *Chlorella vulgaris* Beyerinck. Some of the palmelloid green cells were identified as "apparently a species of *Chlamydomonas.*"

In addition, *Scenedesmus bijuga* (Turp.) Lag. and *Oocystis parva* West and West were found in cultured material, but these species were not observed in the material from the slides. It is possible that *O. parva* was present but unrecognized. On the rose bengal agar plates for fungus studies, *Chlorella vulgaris* formed occasional imbedded or superficial lens-shaped, dark green colonies.

Cyanophyta

1. Filamentous species. The two filamentous blue-green algae found growing on the slides were identified ‡ as *Phormidium uncinatum* (Ag.) Gom. and *Amphithrix janthina* (Mont.) Born. and Flah. The appearance of the *Amphithrix* was atypical, characteristic of the species in habitats where it is overgrown by other algae, as it often had curved and branched filaments instead of the upright, parallel filaments mentioned in descriptions of this species. Larger trichomes, which have been named var. *torulosa* (Grun.) Born. and Flah., were present, but the larger and smaller trichomes were considered as having a common origin.

2. Coccoid species. Most of the coccoid blue-green cells found on the slides from the standard-rate filter formed a Pleurocapsa-like growth of clumps of tightly packed cells. *Anacystis montana* (Lightf.) Drouet and Daily was of scattered occurrence on the slides. Drouet listed the Pleurocapsa-like growth as a parasitized form, possibly originating from *A. montana*, *Entophysalis vulgaris* (Kutz.) Drouet, or one of the Nostocaceae or Stigonemataceae.

* P. S. Conger, U. S. National Museum, Washington, D. C.

† G. W. Prescott, Michigan State University, East Lansing, Mich.

‡ F. Drouet, Chicago Museum of Natural History, Chicago, Ill.

Problems of Algal Counting

The accuracy of the estimates of algal numbers was limited by two general factors: (a) the limitations and errors involved in making the algal counts, and (b) the degree of uniformity of algae on the filters. The counting method presented several limitations in addition to the usual statistical errors involved in making plankton counts. The method of preparing samples, originally designed for enumeration of the fungi, had the disadvantage of making some algae difficult to recognize. *Phormidium* and *Amphithrix* had to be combined in counting because of this disadvantage. The *Chlorococcum* and *Pleurocapsa* types often appeared in clumps, and the number of individual cells in a clump was sometimes difficult to determine accurately. In the case of filamentous algae, each filament or fragment was counted as one unit. With *Stigeoclonium*, where fragments were much branched and widely varying in size, the numbers were only of general value as indicating the comparative abundance of this species from one group of slides to another.

Seasonal Appearance

Gross observations indicated that the most irregularly distributed growth was on the standard-rate filter, where the growth of *Stigeoclonium*, in particular, was spotty. This probably accounted for widely fluctuating numbers of *Stigeoclonium* in the counts. For example, on November 21, 1954, scattered patches of *Stigeoclonium* were observed on the standard-rate filter, but none was detected on the slides collected on that date.

Although the filters appeared green from the beginning of the study, the first visible evidence of algal growth on the slides was observed on January 3, 1955, when the bottom surface of the slides from the high-rate filter showed green. Examination revealed the algae to be predominantly of the *Chlorococcum* type, together with a few *Nitzschia* cells. A few *Chlorococcum*-type cells were found on the tops of the slides from the standard-rate filter.

The first slides examined quantitatively were those collected on February 21, 1955. Scrapings from the rocks on the high-rate filter collected at that time were cultured in Gerloff's medium and growth of *Chlorococcum*-type and *Amphithrix janthina* was obtained. There are scattered records for *Amphithrix* on the slides from the high-rate filter from March through May, but some of these records are questionable, as they may represent misidentified fragments of fungus mycelium. Similar material was found on the standard-rate filter during that period, but it did not occur in sufficient numbers to be detected by the counting method. In later samples, *Amphithrix* was better developed and could be determined more definitely. *Phormidium uncinatum* was detected in abundance on the slides from both filters on May 30, and remained present for the duration of the study.

Stigeoclonium appeared on the filters during the summer months and, when well developed, covered the high-rate filter slides with a mat of green material. Tangled among the bases of the *Stigeoclonium* growths were clumps of *Chlorococcum*-type and large numbers of *Nitzschia* cells. Slides from standard-rate filters with well-developed growth had an entirely different appearance. They were often covered with a flat brownish pad of *Phormidium*, entangled with other algae. The appearance of the algal growths on the rocks of the two types of filters was somewhat different—dense green on the high-rate filter rocks, with a much spottier growth on the standard-rate filter rocks. An exception occurred in the center of the filter where continual leakage created high-rate filter conditions and the growth had the same dense green appearance as the high-

rate filter growths. The growths were non-homogeneous, generally appearing in separate patches of the different types, and frequently overlapping. Except for the presence of *Pleurocapsa*-type cells on the standard-rate filter, the same species of algae were common on both types of filter. Differences in the algal biotas of the filters consisted in the relative importance and abundance of the various species.

Summary

The basic slime layer on trickling filter stones is composed of a complex of microscopic organisms including bacteria, fungi, algae, and protozoans. Of these, the fungi and algae appear to make up most of the basic attached materials with colonies of bacteria, fungi, algae, and individuals of protozoans developing within or upon the basal mat. It appears inaccurate to refer to this complex as a "zoogloeal growth" (18) because it includes filamentous organisms as well as bacterial colonies of zoogloeal and other types. Most of the organisms present in the surface film on the top of the trickling filters studied appear to be capable of colonizing any surface offered, so that use of glass slides for their study seems feasible.

Members of the populations of fungi studied could have been derived from local populations since they are common organisms in the environments that drain into the Dayton, Ohio, sewage system. A few species of less common occurrence are more restricted in distribution or in habitat requirements. The observed algal species are normal inhabitants of trickling filters and other places where polluted waters are found. Members of these two groups of organisms have become acclimated to the environment wherein they are continually bathed in a flow of sewage. Their oxygen requirements are satisfied by continual exposure to the air and their food requirements appear to be fully met by the nutrients occurring in the settled sewage and in the by-products of metabolic processes of other organisms in the filter.

Surface films on trickling filters or in areas of trickling filters receiving a continuous flow of sewage appear to have a definite structure (Figure 4). Underlying the mat and at least partially imbedded in the interstices of the porous slag rock is a layer of fungus mycelium, bacterial cells, algal cells or bases of filaments and holdfasts, and protozoa including sessile-stalked species attached to the stone. From this fundamental layer arises a mass of tissue including fungal and algal filaments, clusters of bacterial cells, fungi, and algae, and free-swimming protozoans and nematodes. Overlying this mass of material is another layer of fungus cells through which algae rarely penetrate but in which yeasts, bacteria, and protozoans are found.

The sloughing process is still incompletely understood but is attributed to one or more of several phenomena including: (a) the grazing or scouring activities of insect larvae, snails, and filter worms; (b) the occasional development of septicity in the lower portions of the film; (c) the mechanical action of sewage application after a quiescent period; and (d) the development of excessive amounts of growth on the stones which cannot be held by the parental organisms at the base of the slime layer. As a result of observations made during the course of this study, the first and second hypotheses do not appear tenable for the filters under consideration. Following periods of excessive precipitation, when the filters receive an excessively high liquid loading, there appears to be more sloughing than at other times. Overproduction of slime components seems to play a part in sloughing toward the end of the summer season. Although the growth peaks show a semiannual pattern for fungi, this pattern is not

reflected as sloughing in the over-all analysis of the slide weights.

On trickling filters receiving a flow of sewage during only part of each day, a less clear pattern of slime development occurs. In many places the fundamental layer of fungi, bacteria, and protozoans appears to be the only growth on the stones. Occasionally this layer is broken by spots of green algae where the pattern is much the same as that already described, or where small to large pads of blue-green algae occur as separate colonies. The same type of colonies appear on the Glendale, Ohio, filter during its periods of intermittent flow. Such pads are almost solid mats of algal filaments and the arrangement of bacterial and protozoan growth within and around them is different than that for the typical filter slime.

Conclusions

The use of glass slides has been found to be an effective method of sampling the populations of microorganisms occurring on the surface of trickling filters. Isolation techniques of this study permitted the consideration of only fungi and algae, but it is recognized that bacteria and protozoans contribute important segments to the total population.

The mat on filter stones continuously receiving sewage appears to have a definite structure, while that on stones receiving an intermittent flow is more heterogeneous.

Sloughing is related more to the vigorous washing of excessive growth on the filters under consideration than to development of a septic layer at their base or to browsing or grazing of metazoal populations.

During a year the populations of the high-rate filter appear to be relatively uniform, although during the winter adverse conditions may reduce the algal populations and in the late winter and spring months *Fusarium aquaeductuum* may show marked increases. Standard-rate filter populations are governed by the intermittent flow of sewage and are much more erratic.

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NTTCIW MEETING REPORT, DECEMBER 1957

Fifty-six scientists and engineers, representing major industries in the United States and representatives of the U. S. Public Health Service, convened at the headquarters of the U. S. Public Health Service December 12 and 13, 1957, for the annual meeting of the National Technical Task Committee on Industrial Wastes. Frank J. McKee of the Kraft Foods Company, Chicago, Illinois, presided.

This Committee is a voluntary group formed to work with the Public Health Service of the U. S. Department of Health, Education, and Welfare to protect the nation's water resources from pollution and contamination. These meetings also provide a forum wherein the members can exchange information on the common problems of waste treatment and disposal.

At the opening session Edward F. Wilson, Assistant Secretary, Department of Health, Education, and Welfare, emphasized the importance of water in the present and future economy of the United States. Leroy Burney, Surgeon General, cited the responsibility of the Public Health Service under the law and the importance of government, state, and industry cooperation in the area of water pollution.

Mr. Mark Hollis, Assistant Surgeon General, pointed out that research expenditures for the years 1950–57 exceeded the total spent from 1776–1950. This has resulted in rapid industrial growth and growing waste treatment problems. Reports indicated that industry is vigorously attacking the problem and supporting a philosophy of over-all water management. The major automobile manufacturers alone have put into operation ten treatment plants in the past year.

Brig. General J. L. Person, Assistant Chief of Engineers, at a luncheon session described the activities of the Corps of Engineers. Results of projects of the Corps include the storage of water, not only for flood control purposes, but also to augment increased river flow rates which complement the activities of the U. S. Public Health Service in promoting water quality. Brig. General Person stated the rapidly increasing water requirement will result in water storage becoming a primary objective of Corps projects in the future.

The activities in connection with pollution control in the pulp and paper industry were shown in a film by Dr. Harry W. Gehm and Mr. Russell L. Winget of the National Council for Stream Improvement of the Pulp, Paper and Paperboard Industries.

A report on the functions of the Federal Inter-agency Committee on Water Resources was given by Mr. Gladwin E. Young, Deputy Administrator, Soil Conservation Service, USDA.

A report was also given of the present status of saline water conversion by W. S. Gillan, Office of Saline Water, U. S. Department of the Interior.

The four task groups of the Committee (food products, mineral products, chemical processing, and general industry) discussed separately their common problems, research activities, and recommendations for activities of the Task Committee. Reports were given by the respective Task Group Chairmen, A. J. Steffen, L. R. Allott, F. R. Pitt, and R. S. Glynn.

Dr. Richard Hoak of the Mellon Institute was elected Chairman of the Committee; Mr. R. S. Glynn of the Association of American Railroads was elected Vice-Chairman; and L. F. Warrick of the Public Health Service was elected Secretary-Treasurer.

VARIATION OF SEWAGE FLOW IN A COLLEGE TOWN

By Gary D. Hutchinson and E. Robert Baumann

Respectively, Student and Professor of Civil (Sanitary) Engineering, Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa

The flow of sewage from any community varies hourly, daily, weekly, seasonally, and annually. Sewage flow also varies with the size and geographical location of communities. Flow variations are important in designing sewerage facilities and treatment plants. The controlling factors in sewer design are the maximum and minimum sewage flow rates. Sewers must provide sufficient capacity to handle the maximum flow. At the same time they must provide flow velocities that will prevent sludge deposits in the sewers when the flow is at a minimum. These fluctuations in flow are also important in the design and scheduling of pumping equipment.

The variation in sewage flow is also an important consideration in a sampling program where the strength of the sewage is to be determined. A sample taken aimlessly, or an average of samples taken without prior flow studies, cannot be expected to show the true characteristics of the sewage. The unit hydraulic and organic loadings on the treatment plant depend on the fluctuations in sewage flow, and a proper design cannot be made without knowledge of these fluctuations.

It seems unusual that published data, even the proposed manual for sewer design (1), depicting such an important design feature as the sewage flow variation should be based on data collected in the 1910–20 era. The high standard of living now enjoyed by the majority of the American people have made these data of little value. A few studies in sewage flow variation have been made within the 1947–56 decade, but most of them were made on the West Coast and are of a limited value generally. It seems unreasonable to expect that the flow variation from a city of the 1910–20 era approximates the flow variation in the same city today. It is also unreasonable to expect that the flow variation from a city on the West Coast will be similar to that from a Midwestern or Eastern city. Thus, it may be concluded that a greater number of sewage flow studies should be made so that more data can be furnished with regard to community size, location, and occupants.

Work Reported by Others

A review of the published information showed a lack of data pertaining to the variation in sewage flow. Some data were found in sewage text books, but most could be traced back to the investigations from 1900 to 1920. These investigations were made on the sewage flow variations of large cities, such as Toledo, Ohio. Some of the texts show "typical curves," but tell nothing of the size or geographical location of the city or cities for which the curves are typical.

Various sewage surveys have been made in California in the last ten years. The surveys, made over entire counties by a board of consulting engineers (2)(3)(4), contain more data pertaining to sewage flow variation than other available material. Although the material presented is unquestionably of good quality, it was collected from sewage flow variation measurements of short periods, no longer than a week, for daily and

TABLE I.—Relationship Between Monthly Flows for Ames, Iowa, and Selected Cities * (Expressed as percentages of the monthly mean)

Month	Ames, Iowa (1956)			18 Cities
	College	City	Total	
Jan.	98	85	91	92
Feb.	97	85	90	93
Mar.	104	105	105	100
Apr.	111	113	112	103
May	119	122	121	108
June	107	116	121	106
July	97	105	102	107
Aug.	94	102	99	104
Sept.	84	89	87	100
Oct.	105	104	104	100
Nov.	97	87	91	94
Dec.	88	87	87	92

* Gary, Ind.; Marshalltown, Iowa; Aurora, Ill.; LaMesa, Calif.; Lemon Grove, Calif.; National City, Calif.; North Island, Calif.; San Diego, Calif.; Anaheim, Calif.; Buena Park, Calif.; Fullerton, Calif.; Garden Grove, Calif.; LaHabra, Calif.; Newport Beach, Calif.; Orange, Calif.; Placentia, Calif.; Santa Ana, Calif.; and Orange County, Calif.[1]

hourly variations. No seasonal data on flow variations could be found.

By studying the annual operating reports of various plants, data were available pertaining to the monthly variation in sewage flow for periods of one to four years. The average monthly flow variations based on data from 18 cities are shown in Table I. The monthly flow was expressed as a percentage of the mean monthly flow for each city. These percentages seemed to show a large discrepancy from year to year without any indication of the cause. Possibly there is a pattern of flow which is determined by the weather, but with data covering only a short time these patterns could not be evaluated. The flow variations shown in Table I should be considered a typical pattern, not necessarily portraying the flow variation for any particular type of city. In all the data assembled, the maximum flow occurs in May, June, or July, and the minimum in December.

Table II shows the averaged daily flow variations occurring during the week for a group of 10 cities. In a typical large city (over 50,000 population) the peak flow was on Saturday, and in a small city (less than 50,000 population) the peak flow occurred on a Monday or Tuesday.

The average hourly variations in the sewage flow of 13 cities are shown in Figure 1. The curves in Figure 2 show that larger cities have a slightly more stable flow than the smaller cities. Once the pattern is established, however, it does not seem to vary appreciably throughout the year. A comparison of the hourly sewage flow variations for the 1910–20 era and that of the 1947–56 decade is shown in Figure 3. It should be noted that in 1916

TABLE II.—Relationship Between Daily Flow Variation for Ames, Iowa, and Selected Cities* (Expressed as percentages of daily mean)

Day of Week	Ames, Iowa (1956)			Average 10 Cities	Population Over 50,000	Population Under 50,000
	City	College	Total			
Sunday	81	83	82	85	82	88
Monday	107	105	106	105	101	108
Tuesday	103	105	104	105	103	106
Wednesday	101	106	103	103	104	101
Thursday	102	105	103	102	100	103
Friday	104	104	104	103	103	103
Saturday	103	92	98	99	104	93

* LaMesa, Lemon Grove, National City, North Island, San Diego, Combined (San Jose, Campbell, Burbank, and Sunal), Orange County, and Santa Clara, Calif.; and Vancouver, B. C.

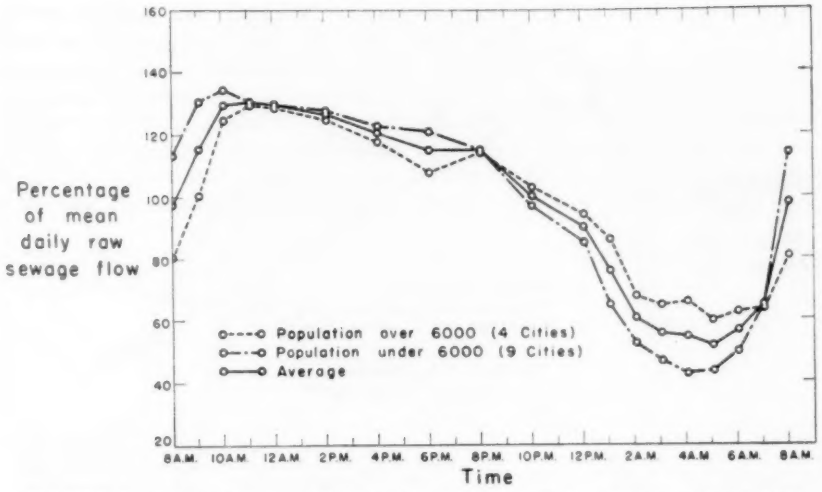

FIGURE 1.—Sewage flow variations in cities with populations under and over 6,000.

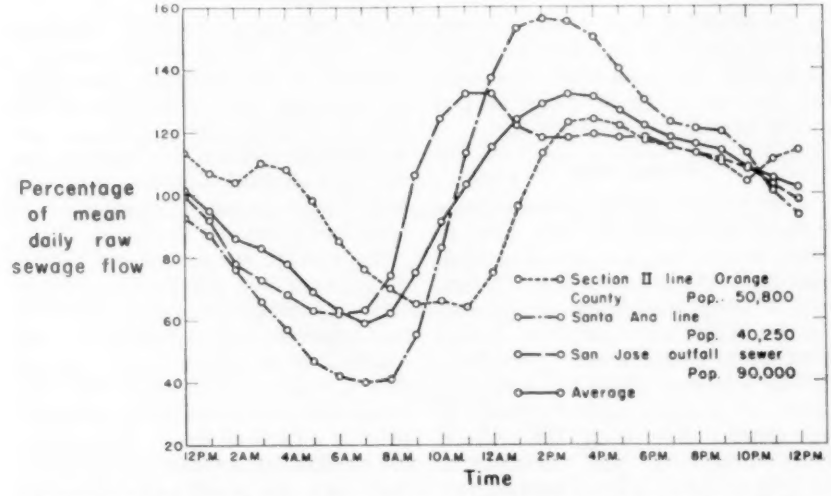

FIGURE 2.—Sewage flow variations in cities with populations from 40,000 to 90,000.

the flow reached a peak at 8:00 AM and a minimum value at about 1:00 AM (5). In 1945–52, the flow peaks between 10:00 and 11:00 AM and reaches a minimum about 5:00 AM. These data would indicate that the average population rises several hours later in the morning and goes to bed several hours later. Of course, the data could reflect the effect of improved transportation facilities both in reducing the rising time and in lengthening sewer time by encouraging the growth of suburbs.

In Figures 1, 5, and 6, the sewage flow variations are expressed as a percentage of the mean daily flow, and the day was taken as the time between 8:00 AM on the test day and 8:00 AM

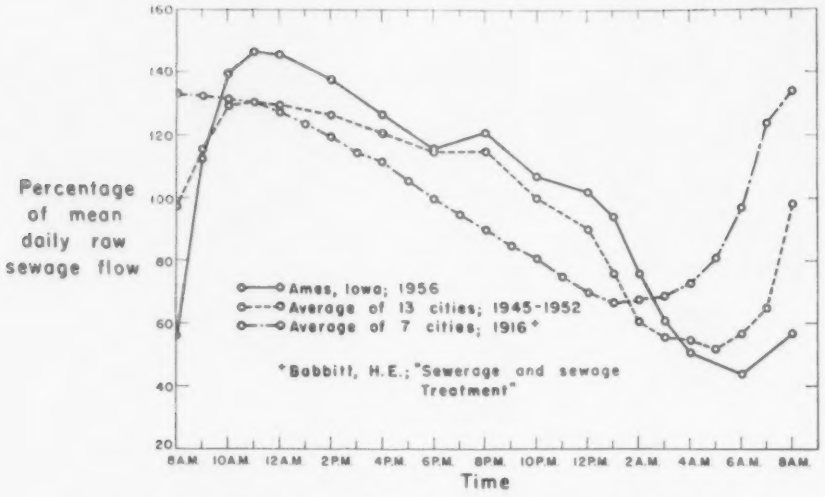

FIGURE 3.—Trend of hourly sewage flow variations from 1916 to 1956.

on the following day. Figure 2 shows the flow variation expressed as a percentage of the mean daily flow with the day beginning at midnight and ending at midnight the same day.

Ames, Iowa

A study of sewage flow variation was recently completed for the City of Ames, Iowa. Ames, a city of approximately 17,000, and Iowa State College, with a school population of approximately 10,000, are located in central Iowa on the Skunk River. Iowa State College is located within the Ames city limits. A separate study was made of the sewage flow from the college. There is only one "wet" industry in the City of Ames, a small canning factory which operates for only a short period during the summer. The largest single contributor of sewage to the Ames system is the Iowa State College campus, which includes the Ames laboratory of the Atomic Energy Commission.

The treatment plant handles the flow from the city's sanitary sewer system only; storm water is carried in separate sewers. The Ames treatment plant has been described elsewhere (6). About 2 mgd of raw sewage is received at the treatment plant daily. In a normal year, 55 per cent of this flow is from the city and 45 per cent is from the college. A basis is thus provided on which both the initial costs and annual operating expenses of the treatment plant can be shared.

To provide for an accurate means of payment, the college flow and the total city-college flow are measured by two separate metering devices. The college flow is metered at the campus in a Kennison nozzle. The total combined flow is measured at the treatment plant in a Parshall flume. Both meters are checked for accuracy on a monthly basis and are recalibrated when the meter error is greater than 1 per cent. The percentage of flow coming from the college and the percentage of the costs to be allocated to the college are thus readily available. Because these data are recorded continuously, raw data pertaining to the flow of sewage from both the college and the City of Ames may be easily gathered.

The Iowa State College sewage flow is measured twice, once at the edge

of the campus and again 2.7 miles away at the treatment plant. The flow measured at the college meter at 8:00 AM, therefore, does not reach the plant, where it will be recorded in the total flow on the Parshall flume, until about 10:00 AM, 2 hr later. This 2-hr time difference was taken into account when comparing the college flow with the city flow.

Although complete records of sewage flow have been kept by the City of Ames, these records had never been evaluated completely to give an indication of the flow variation characteristics. A sewage flow variation study

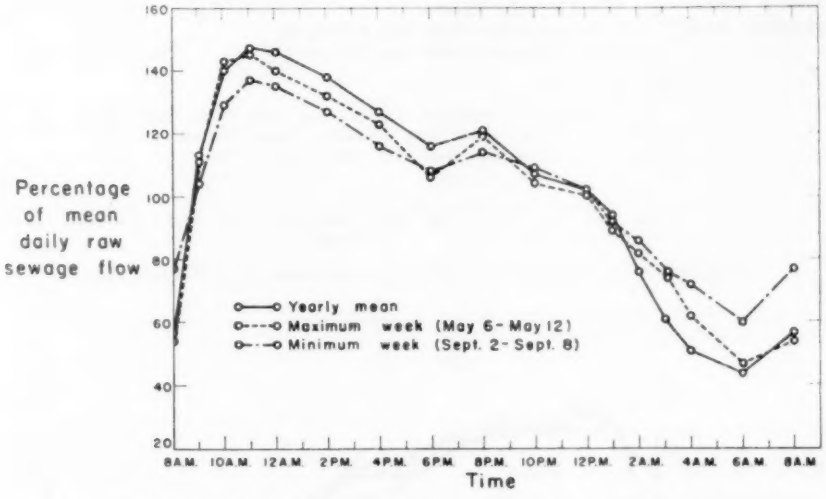

FIGURE 4.—Mean daily total flow variation in Ames, Iowa, 1946.

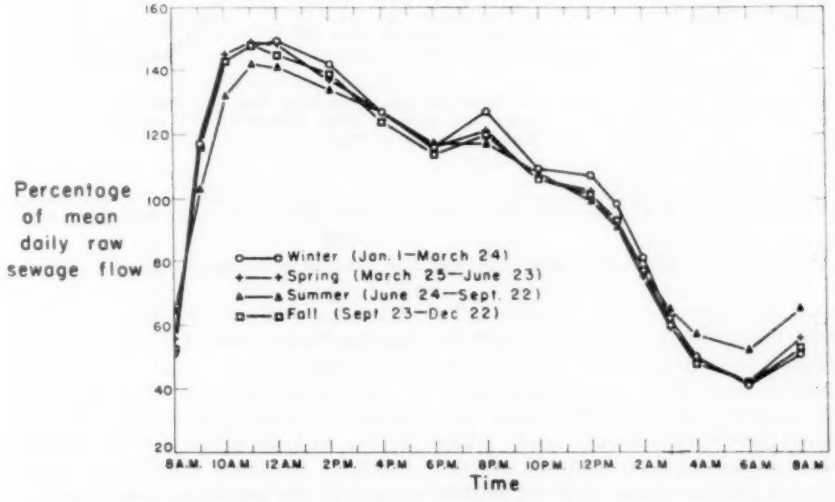

FIGURE 5.—Mean daily total flow variations in Ames, Iowa, by seasons, 1956.

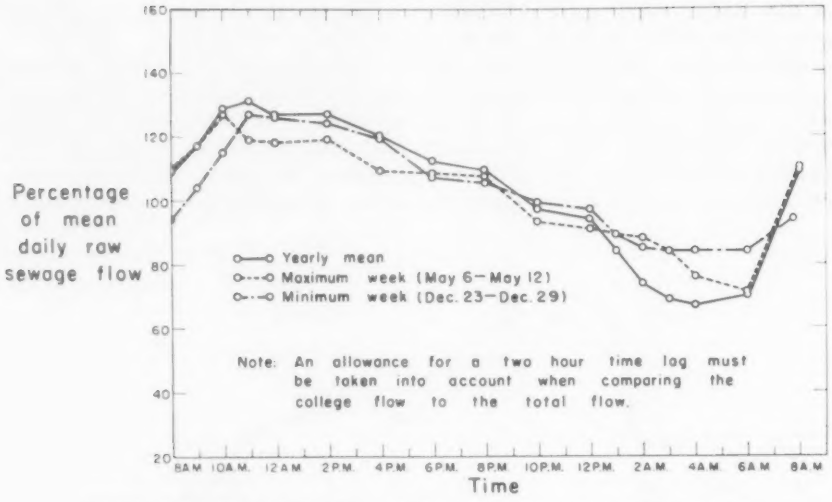
Percentage of mean daily raw sewage flow
160
140
120
100
80
60
40
20
Yearly mean
Maximum week (May 6—May 12)
Minimum week (Dec. 23—Dec. 29)
Note: An allowance for a two hour time lag must be taken into account when comparing the college flow to the total flow.
8A.M. 10A.M. 12A.M. 2P.M. 4P.M. 6P.M. 8P.M. 10P.M. 12P.M. 2A.M. 4A.M. 6A.M. 8A.M.
Time

FIGURE 6.—Mean daily flow variations from Iowa State College, 1956.

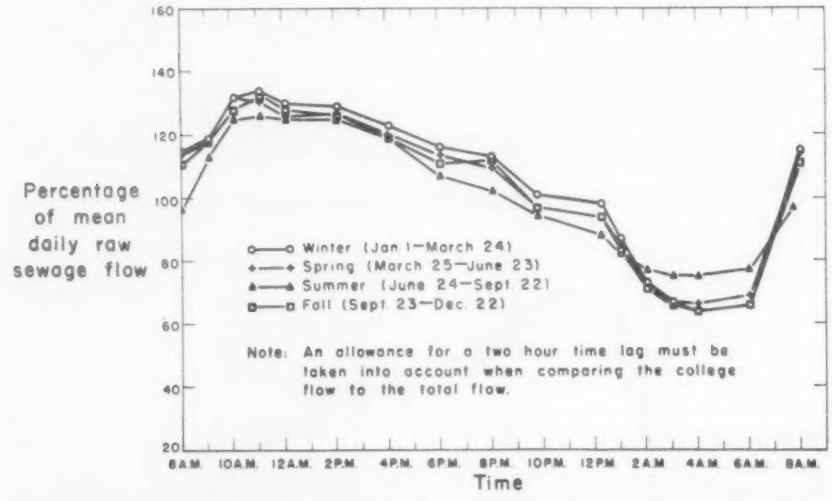
Percentage of mean daily raw sewage flow
160
140
120
100
80
60
40
20
Winter (Jan 1—March 24)
Spring (March 25—June 23)
Summer (June 24—Sept 22)
Fall (Sept 23—Dec. 22)
Note: An allowance for a two hour time lag must be taken into account when comparing the college flow to the total flow.
8A.M. 10A.M. 12A.M. 2P.M. 4P.M. 6P.M. 8P.M. 10P.M. 12P.M. 2A.M. 4A.M. 6A.M. 8A.M.
Time

FIGURE 7.—Mean daily flow variations from Iowa State College by seasons, 1956.

was therefore deemed desirable. To best present flow variation, it is expressed as a percentage of the mean daily sewage flow. A comparison of the hourly, daily, monthly, and seasonal flow variation was made. The time period between 8:00 AM on the date of the flow record and the following 8:00 AM was arbitrarily taken as a day's time, and the flow measured during this period was considered a day's flow.

The values used for the Ames study came from the flow records of 1956, a year with 30 per cent below normal rainfall. The total hourly flow variations for the maximum and minimum weeks, along with the average week,

TABLE III.—Maximum and Minimum Sewage Flows Occurring by Day, Week, and Month in Ames, Iowa, in 1956

Period	Total Flow (mgd)	Date (1956)	Per Cent of Mean
(*a*) City of Ames *			
Max. day	2.478	May 12 (Sat.)	138
Min. day	1.038	Sept. 9 (Sun.)	57
Max. week	2.077	May 6–12	115
Min. week	1.251	Sept. 2–8	70
Max. month	1.977	May	110
Min. month	1.567	Sept.	87
(*b*) Iowa State College †			
Max. day	1.056	May 22 (Tues.)	126
Min. day	0.445	Jan. 1 (Sun.)	53
Max. week	1.001	May 6–12	120
Min. week	0.598	Dec. 23–29	72
Max. month	0.972	May	116
Min. month	0.753	Jan.	90

* Yearly mean daily flow (including Iowa State College flow) = 1.80 mgd.
† Yearly mean daily flow = 0.838 mgd.

are shown in Figure 4. The seasonal changes in hourly flow variation are shown for the Ames total flow in Figure 5. These figures show that the variations from the average values are not great. The variations suggest that it would be feasible to use published data covering only a week's time in a comparison.

The monthly flow variations for the city and college are shown in Table I, and the daily sewage flow variations are shown in Table II. Table III shows a comparison of the maximum with the minimum monthly, daily, and hourly flows for both the college and the City of Ames. The college hourly flow variation is shown in Figures 6 and 7. The college flow is usually steady, except during holiday and vacation periods.

Conclusion

Most published flow data are based on studies of sewage flow in the 1910 to 1920 era. The changes in people's living habits and standards of living indicate that such studies might be seriously outdated. A modern sewage flow study was made for the City of Ames, Iowa, with a population of 27,000. This study should demonstrate the need for a nationwide sewage flow study in cities of various sizes. Such a study would provide more up-to-date data for determining the ratio of maximum sewage flow to average flow for use in sewerage and treatment plant design. The Ames flow study indicates that a week's study of hourly flow variation conducted wisely might portray the sewage flow as well as a year's study.

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STUDIES ON SLUDGE DIGESTION AND METHANE FERMENTATION

II. METHANE FERMENTATION OF ORGANIC ACIDS

By K. L. Schulze and B. Naga Raju

Respectively, Assistant Professor, Department of Civil and Sanitary Engineering, Michigan State University, East Lansing, Mich., and Sanitary Engineer, Wayne County Health Department, Eloise, Mich.

For an investigation of the relationship between volatile acids concentration and rate of gas production it was planned (1) to establish a series of laboratory digesters with a known capacity for converting volatile fatty acids to methane. By increasing the volatile acids feed rate in these units in a controlled manner, the effect on gas production could then be studied. This procedure would exclude the possibility that any increase in volatile acids concentration in the units was merely the result of a low fermentation activity.

Buswell and Hatfield (2) have shown that lower fatty acids can be quantitatively fermented to methane and carbon dioxide. The reaction is of the oxidation-reduction type involving water and can be represented by the following equations for acetic acid:

$$CH_3COOH + 2\,H_2O \rightarrow 2\,CO_2 + 4\,H_2 \quad (1)$$

$$4\,H_2 + CO_2 \rightarrow CH_4 + 2\,H_2O \quad (2)$$

The amount of gas produced per mole of acid can be calculated according to the formula developed by Buswell and Hatfield (2):

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O = (n/2 - a/8 + b/4)\,CO_2 + (n/2 + a/8 - b/4)\,CH_4 \quad (3)$$

In which n = number of carbon atoms,
a = number of hydrogen atoms, and
b = number of oxygen atoms in the acid.

Experimentally it is possible to recover 95 to 99 per cent of the calculated amounts of gas under favorable conditions.

Kaplovsky (3) reported that, in digesting sludges, only three volatile acids were found in measurable quantities, namely acetic, propionic, and butyric acid. Hence these three were selected for the purpose of this study. Using this formula the gas produced per mole of acetic acid is:

$$CH_3COOH \rightarrow CO_2 + CH_4$$

60 g → 44 g + 16 g = 44.8 l gas

1 g CH_3COOH = 746.7 ml gas (0°C, 760 mm Hg)

For propionic acid the calculated gas production is:

$$CH_3 - CH_2 - COOH + \tfrac{1}{2}\,H_2O = 1.25\,CO_2 + 1.75\,CH_4$$

74 g = 3 M gas = 67.2 l

1 g propionic acid = 908 ml gas (0°C, 760 mm Hg)

For butyric acid the calculated gas production is:

$$CH_3 - CH_2 - CH_2COOH + H_2O = 1.5\,CO_2 + 2.5\,CH_4$$

88 g = 4 M gas = 89.6 l gas

1 g = 1,018 ml gas (0°C, 760 mm Hg)

Since the gas measurements in the laboratory were all corrected for 25° C and 760 mm Hg, the corresponding gas volumes are:

1 g acetic acid = 815 ml gas.

1 g propionic acid = 991 ml gas.

1 g butyric acid = 1,111 ml gas.

The apparatus and technique used in this study have been described in Part I of this paper (1).

Experimental Results, Series I

Four units were used for the first set of experiments. All contained 1 l of active digesting sludge from the East Lansing, Mich., sewage treatment plant as seeding material. The analytical data of this sludge were as follows:

Total solids (%)	7.3
Volatile matter (%)	43.8
Ash (%)	56.2
Volatile acids (ppm)	420
pH	7.4

Unit No. 1 received 9.65*N* acetic acid solution as feed; unit No. 2 received 4.32*N* propionic acid; unit No. 3 received 4.62*N* butyric acid. Unit No. 4 received no feeding and served as a control. The theoretical amounts of total gas ($CH_4 + CO_2$) expected were:

1 ml of the acetic acid solution = 0.579 g of acetic acid = 472 ml of gas.

1 ml of the propionic acid solution = 0.32 g of propionic acid = 317 ml of gas.

1 ml of the butyric acid solution = 0.406 g of butyric acid = 451 ml of gas.

Unit No. 1, Acetic Acid

Feeding started on the third day at a feed rate of 1 ml of solution (0.579 g of acetic acid per day) which corresponded to a theoretical gas rate of 472 ml per day. The volatile acids concentration in the unit itself at the start was low (420 ppm). Response to the feeding was immediate. The gas rate on the day before feeding was 240 ml, whereas on the day following feeding the rate was 534 ml. These high gas rates were maintained continuously as long as 1 ml of acid solution was fed daily. The average gas rate for a 7-day period was 513 ml per day. This is higher than the theoretical rate and probably is due to some additional gas from the seeding sludge itself. Figure 1 shows the curves for the gas rate, volatile acids, and pH.

From the 10th day to the 17th day, 2 ml of solution (1.158 g of acetic acid) were fed daily, with the exception of one day. Theoretically, a gas rate of 944 ml per day was expected. Again there was an immediate response to the feeding. The gas rate increased from 490 ml to 730 ml on the 11th day. However, the theoretical rate was not reached for any day during this period. The average gas rate was 650 ml per day. Obviously the rate of acid addition was higher than the rate of conversion to methane and carbon dioxide. As expected, the volatile acids concentration in the unit increased from 313 ppm to 1,289 ppm.

The maximum amount of acetic acid that could be quantitatively fermented per liter of digester volume per day apparently was between 0.6 and 1.1 g. There were three days in this run with gas rates of 750 and 760 ml per day. This gas rate, corresponding to a feed rate of 0.93 g of acetic acid per liter of digester volume per day, seemed to be the maximum rate obtainable under the conditions described here.

During the following 13 days, from the 18th to the 30th day, feed rates of 1, 1.5, and 2 ml of solution were tried again. Feed rates of 1.5 and 2 ml proved to be too high. The corresponding theoretical gas rates of 707 and 944 ml per day were not realized. The average gas rate for this period was 465 ml per day, corresponding closely to a feed rate of 1 ml of solution (0.579 g of acetic acid) per day.

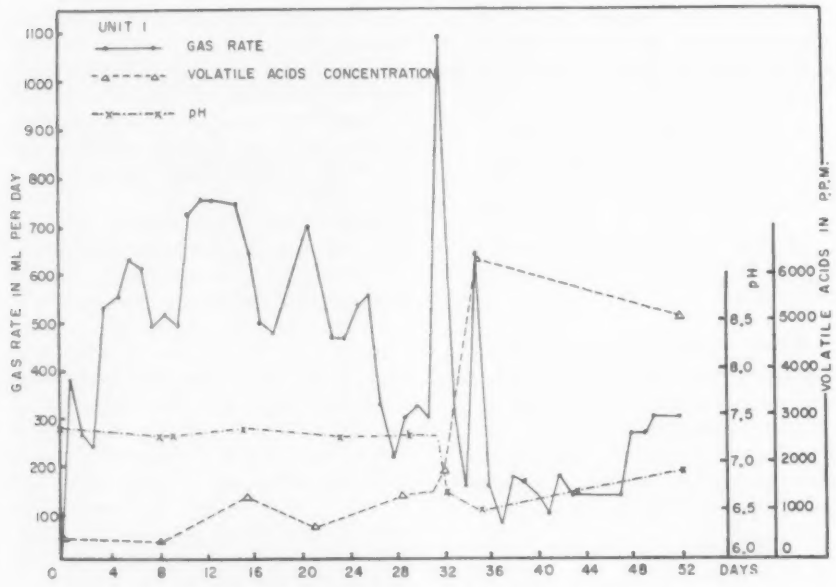

FIGURE 1.—Unit 1 acetic acid fermentation.

On the 31st day one dose of 6 ml of solution (3.474 g of acetic acid) was added. The theoretical gas rate for this feed rate would be 2,831 ml per day. There was an immediate response from the unit, but the gas rate only increased from 300 ml to 1,100 ml on the succeeding day. This was followed by a rapid decrease to 300 ml and 150 ml during the next two days. A repeated dose of 3.474 g of acetic acid on the 34th day brought a temporary increase of the gas rate to 650 ml for one day, following which gas was produced quite steadily at a rate averaging 170 ml per day for the succeeding 17 days without additional feeding. The volatile acids concentration ranged from 6,320 to 5,020 ppm during this period and the pH decreased to 6.5. The theoretical amount of gas for the total of 6.948 g of acetic acid fed would be 5,662 ml; whereas, the actual amount of gas produced during the 22 days of this period was 5,000 ml or 88 per cent of the theoretical amount.

From this experiment it was concluded that a maximum of 0.93 g of acetic acid per liter of digester volume per day could be converted quantitatively to gas. Feed rates beyond this limit resulted in an accumulation of volatile acids and in a decrease of the activity of the methane bacteria. At a range of 5,000 to 6,000 ppm of volatile acids, an average of 170 ml of gas was produced per day; whereas at a range of 300 to 1,300 ppm of volatile acids an average of 650 ml of gas per day was produced.

Unit No. 2, Propionic Acid

Feeding started on the third day and continued until the 23rd day, using 1 ml of solution (0.32 g of propionic acid) corresponding to a theoretical gas rate of 317 ml per day. During the 21 days of this period (Figure 2) gas rates reaching or surpassing the theoretical rate were measured on only three days. The measurments ranged from 310 to 360 ml of gas per day. The average

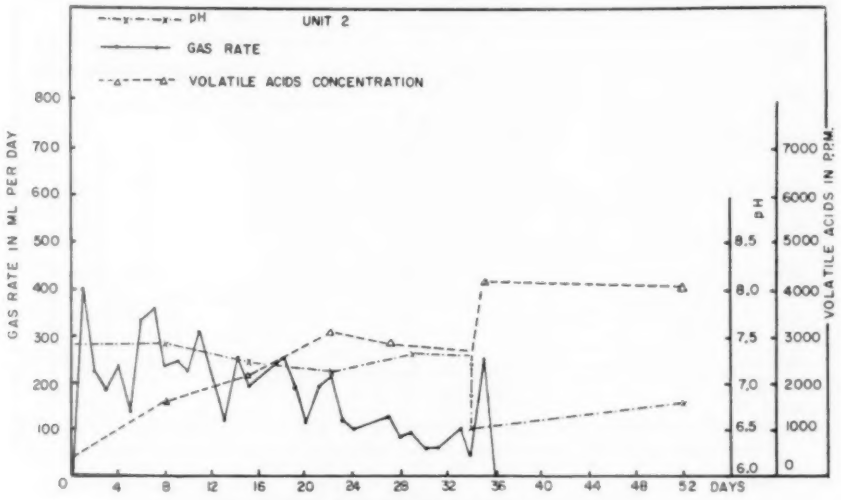

FIGURE 2.—Unit 2 propionic acid fermentation.

gas rate was 210 ml per day, corresponding to a feed rate of 0.21 g of propionic acid per liter of digester volume per day.

Apparently a feed rate of 0.32 g of propionic acid per day was too high. Consequently the volatile acids concentration in the unit increased from 420 ppm at the start to 3,050 ppm on the 22nd day.

From the 25th day to the 33rd day, 0.5 ml of solution (0.16 g of propionic acid) was fed per day in an attempt to decrease the accumulated volatile acids. This failed as evidenced by the fact that the average gas rate was 76 ml against a theoretical rate of 158 ml per day. Apparently the previously accumulated volatile acids concentration of 3,050 ppm was high enough to impair methane fermentation. A decrease in pH was not involved, since the pH stayed between 7.1 and 7.3 during this period. A single addition of 10 ml of solution (3.2 g of propionic acid) on the 34th day caused the gas rate to drop to zero and the unit did not recover during the following 18 days of continued observation.

Unit No. 3, Butyric Acid

One milliliter of solution (0.406 g of butyric acid per day) corresponding to a theoretical gas rate of 451 ml, was fed from the third to the 9th day. The unit received a total of 2.842 g of butyric acid, corresponding to 3,157 ml of gas. An actual amount of 3,410 ml of total gas was produced and the average gas rate was 528 ml per day. The excess gas was probably due to additional gas from the seeding material. Figure 3 shows the curves for the gas rate, volatile acids, and pH record for Unit 3.

During the second period beginning with the 9th day, 2 ml of solution (0.812 g of butyric acid) were added daily. The expected gas rate was 902 ml per day. The unit produced 1,030, 1,050 and 1,085 ml of gas on the 12th, 13th, and 14th days. Due to a leak, the measurements on the other days were incorrect.

From the 18th to the 23rd day, 3 ml of solution (1.221 g of butyric acid) were added daily, corresponding to 1.356 ml of gas per day. A total of 7.326 g of butyric acid was fed, cor-

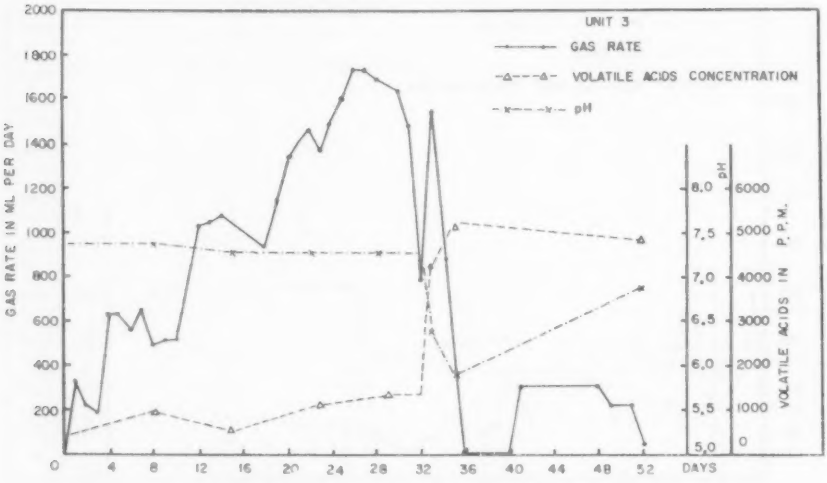

FIGURE 3.—Unit 3 butyric acid fermentation.

responding to a total of 8,139 ml of gas. The actual yield was 7,560 ml of gas. The average gas rate was 1,340 ml per day, representing 99 per cent of the theoretical rate.

During the fourth period beginning with the 24th day, 4 ml of solution (1.628 g of butyric acid) were added daily for seven days. The expected gas rate was 1,804 ml per day. A total of 11.396 g of butyric acid was added, corresponding to a total of 12.628 l of gas. An actual yield of 11.285 l of gas was recorded. The average gas rate was 1,654 ml per day, representing 92 per cent of the theoretical rate. The volatile acids concentration in the unit had increased to 1,320 ppm.

On the 32nd day and the 34th day, single doses of 8 ml of solution (3.256 g butyric acid) were added. On the 36th day methane fermentation ceased and the gas rate remained at zero for the following six days. On the 42nd day, gas production started again, but remained at a relatively low level averaging 272 ml per day for 11 days at which time the experiment was terminated. The volatile acids concentration had increased to 5,770 ppm and the pH decreased to 5.9.

According to these data 1.6 g of butyric acid per day per liter of active digester volume was the maximum feed rate. Addition of 3.256 g of butyric acid was sufficient to inhibit methane fermentation completely for several days.

Unit No. 4, Control; Seeding Material Alone

The gas rate during the first period from the 3rd to the 10th day averaged 146 ml per day. From the 10th to the 20th day, the gas rate decreased sharply to an average of 43 ml per day. From the 21st to the 34th day, approximately 10 ml of gas were produced per day, following which gas production ceased completely. The fact that the gas rates exceeded the theoretical values in units No. 1, 2 and 3 during the first feeding periods was therefore explained by additional gas from the seeding material. After the 10th day, these additional amounts of gas were negligible as compared to the gas rates in the acid fed units and therefore no corrections were made for them. Figure 4 shows the gas, volatile acids, and pH curves for the control.

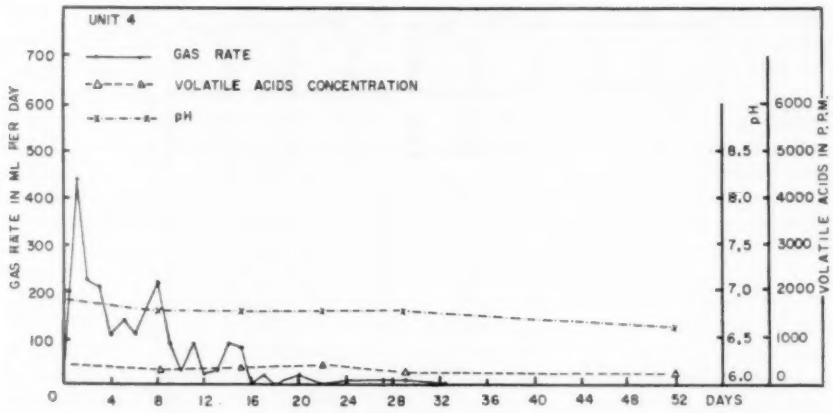

FIGURE 4.—Series I control unit gas rates, volatile acids concentrations, and pH values.

Experimental Results, Series II

The second series of experiments employed the use of pure acids and compounds of ammonia and potassium. Seven units were used, two parallel units for each of the three acids and one control unit which received no feeding. All units contained 1 l of active sludge from the East Lansing digester as starting material. Data for this starting material were as follows:

Total solids (%)	6.2
Volatile matter (%)	34.0
Ash (%)	66.0
Volatile acids (ppm)	610
pH	7.1

In the preceding series of experiments, the pH dropped below 7 each time the feed rates were increased considerably beyond the optimum range. In order to avoid this drop in pH, acetic, propionic, and butyric acid solutions of known normality were titrated with ammonium hydroxide or potassium hydroxide to a pH of 6.0. The resulting solutions were then used for feeding. A pH of 6.0 was chosen in order that the addition of alkali to the units be kept to a minimum.

The pure acid solutions contained the following amounts of acid per milliliter:

Acid	Quantity (g)
Acetic	0.283
Propionic	0.348
Butyric	0.418

The ammonium compound solutions were of the same strength, whereas 1 ml of the potassium compound solutions corresponded to:

Acid	Quantity (g)
Acetic	0.316
Propionic	0.388
Butyric	0.464

Units A1 and A2, Acetic Acid

During the first 12 days Unit A1 received doses of 2, 3, and 4 ml of solution, equal to 0.566, 0.849, and 1.132 g of acetic acid per day. The corresponding theoretical gas rates were 461, 692, and 922 ml per day. The three highest gas rates measured were 750, 780, and 800 ml per day. This indicated that the previously established maximum feed rate of 0.93 g of acetic acid per liter of digester volume per day was close to the actual value and could be reproduced. The total amount of acid fed during the first 12 days was 8.367 g, corresponding to a theoretical yield of 6,819 ml of gas. The actual amount of gas measured was 7,860 ml. The excess gas of 1,041 ml was probably due to additional gas from the seeding ma-

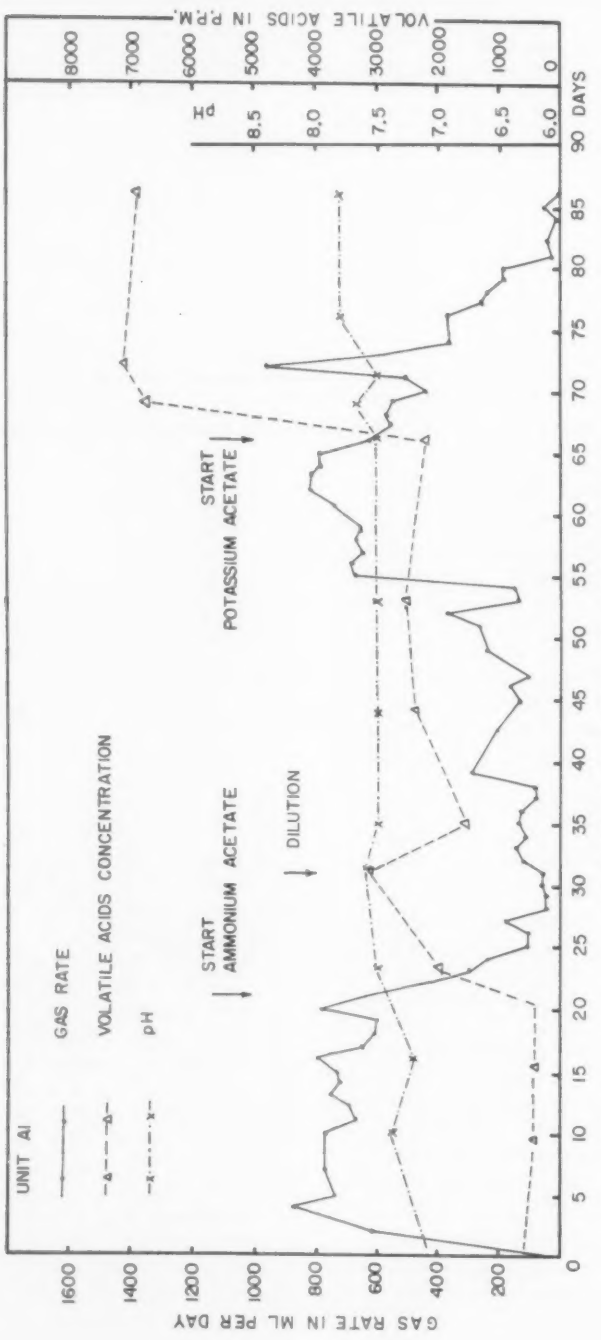

FIGURE 5.—Unit A1 acetic acid fermentation.

terial. The control unit D (Figure 8) produced a total of 770 ml of gas during the same period. The curves for gas production, volatile acids content, and pH for Unit A1 are shown in Figure 5.

From the 12th to the 20th day, 0.934 g of acetic acid was fed daily in order to establish maximum digester activity. The average gas rate during these eight days was 715 ml per day, equal to 94 per cent of the theoretical rate. Practically all of the acid fed was converted quantitatively to gas. Accordingly, the volatile acids concentration in the unit stayed low during the two periods; 390 ppm were measured on the 8th and 16th days.

The average feed rate for the combined periods (20 days) was 0.88 g of acetic acid per day and the average gas rate was 683 ml per day. This represented 95 per cent of the theoretical average gas rate.

On the 21st day, feeding of ammonium acetate solution was started at a rate of 1.701 g of acetic acid per day. Except for two days, this feed rate was continued until the 26th day. The volatile acids concentration in the unit increased immediately to 2,620 and 2,180 ppm while the pH stayed at 7.5 to 7.6. The average feed rate for the six-day period was equivalent to 1.134 g of acetic acid per day. This corresponded to a theoretical average gas rate of 924 ml per day. The actual average gas rate was 305 ml per day or 33 per cent of the theoretical value. At the end of the feeding period the gas rate decreased to 110 ml per day.

Independent of the pH, an increase of the volatile acids concentration beyond 2,000 ppm in an otherwise highly active digesting sludge, resulted in a marked decrease of the methane fermentation.

To restore the activity of the unit, 1,000 ml of active digesting sludge from the East Lansing sewage treatment plant digester were added on the 32nd day. From the 32nd to the 49th day, several feedings varying from 0.596 to 1.49 g of acetic acid were made and gas production started again at rates up to 300 ml per day.

On the 50th day, 1,000 ml of sludge were removed from the unit so that the original capacity of 1,000 ml was again reached. This also improved the stirring of the material so that the acid solutions added were mixed more quickly with the sludge.

After the 54th day, 0.894 g of pure acetic acid was added daily for a period of five days with the result that the gas rate increased immediately to an average of 668 ml per day, equivalent to 91 per cent of the theoretical value.

From the 61st to the 64th day, 1.198 g of acetic acid were added. The average gas rate increased to 798 ml per day, representing 82 per cent of the theoretical gas rate. At the beginning of this period, the volatile acids concentration in the unit was 2,560 ppm and the pH was 7.5.

From the 66th to the 72nd day, potassium acetate solution was fed equivalent to an average rate of 1.608 g of acetic acid per day. This caused an increase of the volatile acids concentration to 7,200 ppm while the pH remained at 7.5 to 7.7. The theoretical gas rate would have been 1,310 ml per day. The actual average gas rate was 596 ml per day, or 45 per cent of the theoretical value. This was also 17 per cent less than the previously established optimum average gas rate of 715 ml pertaining to a feed rate of 0.934 g of acetic acid per day. With no feed for the following seven-day period, the gas rate averaged 283 ml per day or 39 per cent of the optimum gas rate.

The data show that, with increasing volatile acids concentrations, the gas rate could not be increased beyond a temporary maximum rate of 798 ml per day. With ample food supply present and a pH value above 7, the gas rate decreased to an average of 596 ml

per day at a volatile acids concentration of 2,200 to 7,200 ppm.

On the 80th day a single addition of potassium acetate solution was given equivalent to 3.16 g of acetic acid. The gas rate dropped to 30 ml on the following day and to zero on the 86th day, while the pH stayed at 7.8.

Unit A2 showed essentially the same results. During the first 20 days, feed rates of 0.566 and 0.934 g of acetic acid were used, and the theoretical gas rates of 461 and 761 ml per day were reached without difficulty. The average feed rate was 0.769 g of acetic acid per day and the average gas rate was 595 ml of gas per day, representing 95 per cent of the theoretical value. Volatile acids determinations ranged from 610 to 2,320 ppm during this period. Feeding of ammonium acetate equivalent to an average of 1.134 g of acetic acid per day for six days increased the volatile acids concentration to 2,700 ppm while the pH increased to 7.8. The gas rate decreased to an average of 185 ml per day, representing 20 per cent of the theoretical value.

After restoration of the digesting activity of the unit by the previously described dilution process, a feed rate of 0.894 g of acetic acid was used for 10 days. The average gas rate of 729 ml per day was equal to the theoretical rate.

Slight overloading of the unit by applying a feed rate of 1.198 g of acetic acid per day for four days resulted in a maximum average gas rate of 794 ml per day. This was practically the same as the maximum rate of 798 ml of gas per day experienced under the same conditions in Unit A1. Both values represent 81 to 82 per cent of the theoretical gas rate. The volatile acids concentration stayed at 2,010 to 2,300 ppm during this period.

Feeding of potassium acetate at a rate equivalent to 1.608 g of acetic acid per day for seven days increased the volatile acids concentration to 7,400 ppm and decreased the average gas rate to 542 ml per day or 41 per cent of the theoretical value. Compared with the optimum gas rate of 715 ml per day previously established in Unit A1, this represents 76 per cent of that value. For the following period of seven days with no feeding, the gas rate averaged 327 ml per day at a concentration of 6,800 ppm volatile acids. This represented 46 per cent of the optimum gas rate. A single addition of potassium acetate solution equivalent to 3.16 g of acetic acid reduced the gas rate to an average of 71 ml for the following six days.

Generally, both experiments showed that in the presence of potassium ions a considerably higher volatile acids concentration was tolerated than in the presence of ammonium ions. Nevertheless, an increase of the volatile acids concentration in excess of 3,000 ppm always resulted in a marked decrease of the gas production. This decrease was independent of the pH.

Units B1 and B2, Propionic Acid

These units were started by feeding 0.5 ml and 0.6 ml of pure propionic acid solution, equivalent to 0.174 g and 0.209 g of propionic acid per day. Data for Unit B1 are given in detail (Figure 6). The feed rate of 0.209 g of propionic acid per day was maintained for 12 days and resulted in an average gas rate of 188 ml per day, representing 91 per cent of the theoretical rate. The average feed rate for the first 20 days was 0.2 g of propionic acid. The average gas rate was 208 ml per day as compared to a theoretical rate of 198 ml. The excess gas was due to some additional gas from the seeding material. The agreement with the previously established average gas rate of 210 ml per day in Unit 2 was very good.

Feeding of ammonium propionate solution at a rate equivalent to 0.342 g of propionic acid per day for a period of four days (21st to the 25th day) resulted in a decrease of the gas rate

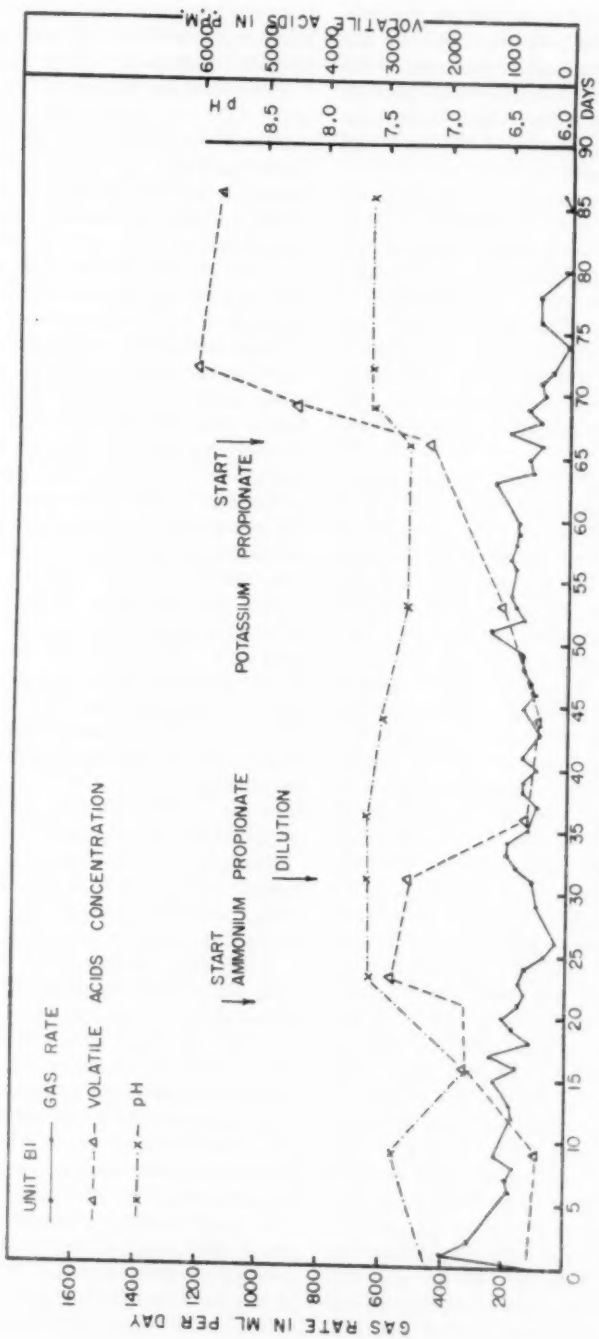

FIGURE 6.—Unit B1 propionic acid fermentation.

to an average value of 140 ml per day. This represented 41 per cent of the theoretical value and 67 per cent of the previously established average rate of 208 ml per day. The volatile acids concentration increased to 2,860 ppm and the pH decreased to 6.8.

After restoration of the digesting activity in the unit by dilution in the same manner as in Units A1 and A2, 0.174 g of propionic acid were added daily for eight days, from the 53rd to the 61st day. The average gas rate was 170 ml per day, close to the theoretical value of 172 ml per day. The volatile acids concentration in the unit was 1,010 ppm at the beginning of this period.

Feeding of potassium propionate solution at a rate equivalent to 0.776 g of propionic acid per day for a period of four days (from the 65th to the 69th day) reduced the gas rate to an average of 125 ml per day, whereas the volatile acids concentration in the unit increased to 4,430 ppm. Thus the average gas rate had decreased to 60 per cent of the previously established optimum rate of 208 ml of gas per day, and to 16 per cent of the theoretical gas rate. The pH ranged from 7.3 to 7.6 during this period. A further increase of the volatile acids concentration to 6,100 ppm by two feedings (0.348 and 0.194 g of propionic acid) caused the average gas rate to drop to 69 ml per day. After one additional feeding of 0.194 g of propionic acid on the 78th day, gas production ceased completely on the 80th day and the unit did not recover until the end of the experiment on the 86th day. The pH stayed at 7.6 during this period.

Again, the results on Unit B2 were very similar to those on Unit B1. The average feed rate for the first 20 days was 0.192 g of propionic acid per day corresponding to a theoretical gas rate of 190 ml per day. Experimentally, an average gas rate of 193 ml per day was found. The small amount of excess gas was due to additional gas from the seeding material. The volatile acids concentration increased from 610 ppm to 2,043 ppm during this period.

Four feedings (from the 21st to the 25th day) of ammonium propionate solutions equivalent to 0.342 g of propionic acid per day increased the volatile acids concentration in the unit to 2,640 ppm and reduced the gas rate to an average of 62 ml per day. This was 18 per cent of the theoretical gas rate and 29 per cent of the previously established optimum gas rate.

After restoration of the digesting activity of the unit, 0.174 g of pure propionic acid was added daily for 10 days. The average gas rate was 193 ml per day with a volatile acids concentration of about 2,000 ppm in the unit. The excess of 21 ml of gas above the theoretical rate was probably due to additional gas from the sludge used for dilution.

For the following period of four days an average feed rate of 0.26 g of propionic acid was used, resulting in an average gas rate of 220 ml or 86 per cent of the theoretical value. Apparently, in full agreement with previous data, a gas rate of 210 to 220 ml, corresponding to a feed rate of 0.21 g per liter of digester volume per day, was the optimum for propionic acid.

Feeding of potassium propionate solution equivalent to 0.776 g of propionic acid per day for three days increased the volatile acids concentration to 4,900 ppm and caused a temporary peak gas production of 380 ml per day followed by a drop to 60 ml per day. Further addition of 0.348 g of propionic acid and 0.194 g as potassium propionate raised the volatile acids concentration to 5,400 ppm. The average gas rate decreased to 110 ml per day for the following six days, representing 50 per cent of the optimum rate.

A final feeding of 0.696 g of propionic acid reduced the gas rate to an average of 70 ml per day for a period of 9 days. The pH stayed in the range of 7.2 to 7.6 during this period.

The greater tolerance of the methane bacteria towards accumulated volatile acids in the presence of potassium ions was also noted in these experiments.

Units C1 and C2, Butyric Acid

In Unit C1, feed rates of from 0.836 to 1.463 g of butyric acid per day were used during the first 20 days. The gas rates followed the feed rates closely. For feed rates of 0.836 g, gas rates of 865 and 930 ml were obtained, as compared to the theoretically expected rate of 928 ml per day. For feed rates of 1.254 g, gas rates of 1,320 to 1,490 ml were recorded as compared to the theoretically expected rate of 1,393 ml per day. For feed rates of 1.463 g per day, readings of 1,540 and 1,600 ml of gas per day were obtained, representing 95 and 98 per cent of the theoretical value. Figure 7 shows the curves for gas rates, volatile acids production, and pH for Unit C1.

The average feed rate for the total period of 20 days was 1.243 g per day, corresponding to a theoretical average gas rate of 1,381 ml per day. The experimental average gas rate was 1,319 ml per day, representing 95 per cent of the theoretical value. As expected, the volatile acids concentration in the unit stayed at a low level of 400 to 470 ppm during this period.

Beginning on the 21st day, ammonium butyrate solution, equal to a feed rate of 2.512 g of butyric acid per day, was added for a six-day period. The volatile acids concentration in the unit increased to 3,830 ppm and 7,250 ppm while the pH stayed at 7.4 to 7.6. The average gas rate was 1,183 ml per day, representing 42 per cent of the theoretical rate and 71 per cent of the previously established optimum rate. Beginning on the 27th day and continuing for five days, there was no feeding. During this period, the average gas rate decreased to 606 ml per day in the presence of 7,250 ppm volatile acids.

To restore the digesting activity of the unit, the same dilution procedure was used as in the previous cases. On the 55th day, feeding of pure butyric acid was started at a rate of 1.248 g per day, and the theoretical gas rate of 1,387 ml per day was realized. A volatile acids check showed 2,200 ppm during this period. On the 60th day, the feed was increased to 1.664 g per day for a period of five days. The corresponding average gas rate was 1,766 ml per day, representing 95 per cent of the theoretical rate. Apparently a maximum of about 1.6 g of butyric acid per liter of digester volume per day could be converted quantitatively to gas. This is in good agreement with the results from the first set of experiments in Unit No. 3 where an optimum average gas rate of 1,654 ml was obtained under similar conditions.

Following the 65th day, potassium butyrate solution equivalent to an average feed rate of 3.10 g of butyric acid per day was added for a period of 13 days. The volatile acids concentration increased to 9,750 ppm and the pH ranged from 7.5 to 7.6 during this period. The experimental gas rate showed an erratic behavior. Peak gas rates of 2,750 and 3,020 ml per day were recorded for single days. The average gas rate was 1,934 ml per day or 56 per cent of the theoretical value. This average gas rate was higher than the average of 1,766 ml per day recorded for the preceding period under optimum conditions, but it represented a maximum rate under unstable conditions. For a period of five days following the 78th day, the average gas rate decreased to 526 ml per day, equal to 29 per cent of the optimum rate. An additional feed of 5.96 g of butyric acid did not change this rate appreciably. The final reading on the volatile acids concentration was 13,300 ppm.

In the presence of potassium ions, volatile acid concentrations ranging from 9,000 to 13,000 ppm had to be reached before the fermentation of butyric acid was markedly depressed.

Unit C2 developed several leaks so

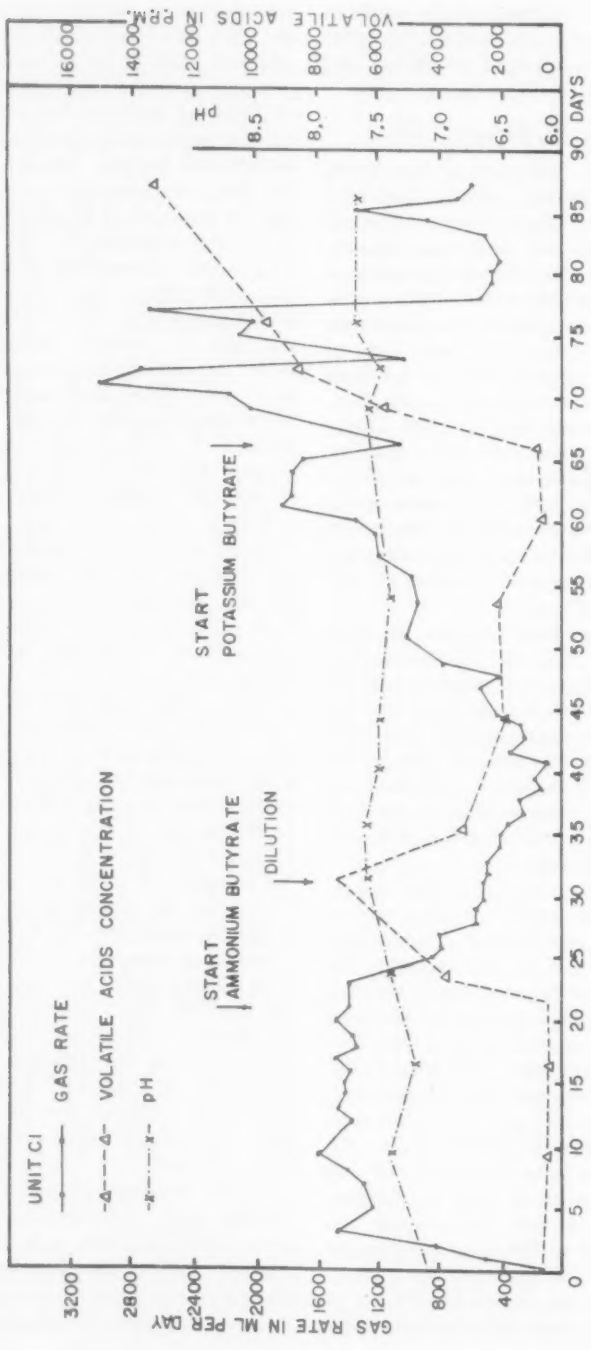

FIGURE 7.—Unit C1 butyric acid fermentation.

that no continuous gas measurements were possible during the first 20-day period; however, gas rates ranging from 1,200 to 1,280 ml per day at feed rates of 1.254 g of butyric acid per day were realized.

The addition of ammonium butyrate solution at a rate equivalent to 2.512 g of butyric acid resulted in an increase of the volatile acids concentration in the unit to 6,150 ppm and a very marked decrease of the gas rate to an average of 345 ml per day. This was equal to 12 per cent of the theoretical rate. Following the 26th day and for a period of six days without feeding in the presence of 8,350 ppm volatile acids, the average gas rate was 272 ml per day. The pH measured 7.6 during this period.

After reactivating the unit by the dilution process as described previously, an average gas rate of 1,417 ml per day was measured over a period of 10 days, beginning with the 26th day, at a feed rate of 1.254 g of butyric acid per day. This was slightly higher than the theoretical rate of 1,391 ml of gas per day and was probably due to some additional gas from the sludge used for dilution. A volatile acids analysis showed 2,450 ppm during this period. A feed rate of 1.664 g of butyric acid per day resulted in an average gas rate of 1,735 ml per day, representing 94 per cent of the theoretical rate. This compares favorably with the optimum average gas rate of 1,766 ml recorded for Unit C1 under parallel conditions.

The addition of potassium butyrate equivalent to feed rates varying from 3.248 to 5.96 g of butyric acid for a period of 13 days, beginning with the 36th day, increased the volatile acids concentration to 8,550 ppm, while the pH ranged from 7.5 to 7.8. The average feed rate for this period was 3.472 g of butyric acid per day. This corresponded to a theoretical gas rate of 3,857 ml per day.

The experimental gas rates showed the same erratic values which were already mentioned for unit C1. Gas rates up to 3,340 ml were measured for single days. The average gas rate of 2,410 ml was even higher than that of 1,934 ml reported for Unit C1 under the same conditions. Nevertheless, this gas rate represented only 62 per cent of the theoretical rate and consequently the volatile acids concentration increased to 11,700 ppm. By a final addition of 5.96 g of butyric acid, the volatile acids concentration rose to 14,200 ppm and the average gas rate decreased to 686 ml per day, equal to 40 per cent of the previously established optimum level. In this case a volatile acids concentration above 11,000 ppm had to be reached before the gas rate was reduced below the optimum level.

In general good agreement existed between the results obtained with Units C1 and C2.

Unit D, Control

The digester sludge from the East Lansing sewage treatment plant used as seeding material in this series of experiments had a low activity. The gas rate decreased to 60 ml per day on the 10th day and to zero on the 20th day (Figure 8).

A total of 1,578 ml of gas was produced in 20 days. Following the dilution procedure on the 21st day, only 10 ml gas per day were developed over a five-day period. Following the 25th day, the gas rate dropped to zero. Since these amounts of gas were negligible as compared to the gas rates developed in the acid fed units, no corrections were made for them.

Data

The results on propionic, acetic, and butyric acid from all units are tabulated in Tables I, II, and III. The tables show that it was possible to feed known amounts of organic acids continuously and to verify the theoretically expected amounts of gas with a

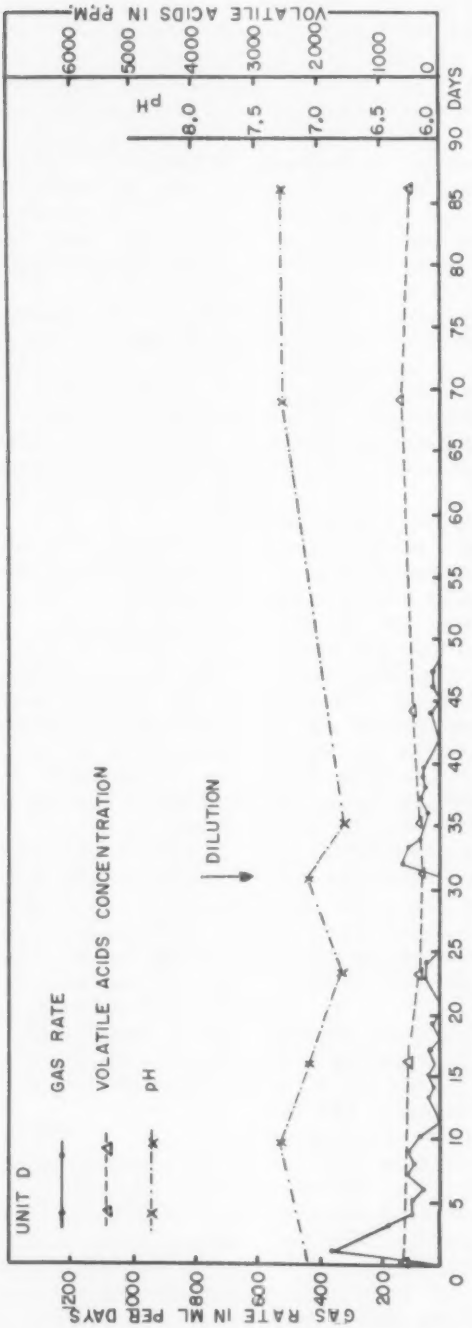

FIGURE 8.—Series II control unit gas rates, volatile acids, concentrations, and pH values.

good degree of reproducibility. There were also definite limits of the feed rates which could be applied without upsetting the fermentation process.

For propionic acid the average optimum gas rates were 208 and 210 ml per day at feed rates of 0.192 and 0.20 g of the acid per day. For acetic acid the average optimum gas rates were 715 and 729 ml per day at feed rates of 0.894 and 0.934 g of the acid per day. For butyric acid the corresponding values were 1,735 and 1,766 ml of gas at a feed rate of 1.664 g of the acid per day.

These rates apparently represent the maximum amount of acid that could be quantitatively converted to gas per liter of active digester volume per day on a continuous basis. The ratio between these rates is close to 1:5:8 for propionic, acetic, and butyric acid. For the gas rates a similar relationship exists. The ratios are close to 1:4:8. Thus it appears that propionic acid is converted at the slowest rate. On a weight basis, acetic acid is converted five times more rapidly and butyric acid eight times more rapidly than propionic acid.

The optimum feed rate for acetic acid was about 1 g per day per liter of active digester volume. In one of their experiments Buswell and Hatfield (2) used up to 2.54 g of this acid per day; however, their digester had 3.5 l of active volume. If this is taken into account, a value of 0.726 g of acetic acid per liter of digester volume per day results. These authors also noted

TABLE I.—Propionic Acid

Unit No.	Days	Feed Rate, Avg (g/day)	Gas Rate, Avg (ml/day)	Per Cent of Theor. Gas Rate	Volatile Acids (ppm)	Substrate Used	Remarks
				(*a*) Series I			
2	9	0.124	75	61	2,850	*	High volatile acids due to previous overloading
B1	8	0.174	170	99	1,010	*	—
B2	8	0.174	193	112	2,100	*	Some excess gas from seeding material
2	20	0.192	210	110	1,584 to 3,050	*	Optimum rate, some excess gas from seeding material
B2	20	0.192	193	101	610 to 2,043	*	Some excess gas from seeding material
B1	20	0.20	208	105	642 to 1,690	*	Optimum rate, some excess gas from seeding material
B1	12	0.209	188	91	642 to 1,690	*	—
				(*b*) Series II			
B2	4	0.26	220	86	2,000(?)	*	Slight overloading, unstable condition
2	18	(3.20)	0	—	over 4,120	*	Overloading by single dose
B1	4	0.776	125	16	4,430	†	Overloading
B2	3	0.776	290	37	4,900	†	Unstable condition
B1	5	—	100	—	5,400	†	High volatile acids due to previous overloading
B1	4	0.342	140	41	2,860	‡	—
B2	4	0.342	62	18	2,640	‡	—

* Propionic acid.
† Potassium propionate.
‡ Ammonium propionate.

TABLE II.—Acetic Acid

Unit No.	Days	Feed Rate, Avg (g/day)	Gas Rate, Avg (ml/day)	Per Cent of Theor Gas Rate	Volatile Acids (ppm)	Substrate Used	Remarks
			(*a*) Series I				
1	7	0.579	513	108	313	*	Some excess gas from seeding material
A2	20	0.769	595	95	610 to 2,320	*	—
A1	20	0.88	683	95	610 to 392	*	—
A1	6	0.894	668	91	2,000 (?)	*	—
A2	10	0.894	729	100	2,010	*	Optimum rate
A1	8	0.934	715	94	390	*	Optimum rate
			(*b*) Series II				
1	8	1.158	650	69	1,300	*	Slight overloading
A1	4	1.198	798	82	—	*	Overloading, unstable condition
A2	4	1.198	794	81	—	*	Unstable condition
1	17	(3.474)	170	—	6,320	*	Overloading by two single doses
A1	7	1.608	596	45	2,220 to 7,200	†	Overloading
A2	7	1.608	542	41	2,300 to 7,400	†	Overloading
A1	7	—	283	—	7,200	†	High volatile acids by previous overloading
A2	7	—	327	—	6,800	†	High volatile acids by previous overloading
A1	6	1.134	305	33	2,700 to 3,200	‡	—
A2	6	1.134	185	20	2,700	‡	—

* Acetic acid.
† Potassium acetate.
‡ Ammonium acetate.

that butyric acid was more readily fermented than acetic acid. When a mixture of both these acids was added to their units, the butyric acid disappeared more rapidly than the acetic acid.

An explanation of the marked difference in fermentation rates between these acids cannot be given here, since the enzymatic reaction mechanism of the methane fermentation is not as yet well understood. From a structural point of view it seems reasonable that the conversion of propionic acid, a three carbon molecule, is more complex than that of acetic or butyric acid, which are two and four carbon molecules.

Tables I, II and III show that whenever the feed rates were increased beyond the optimum levels of 0.2, 1.0 and 1.6 g per day for propionic, acetic and butyric acids, respectively, the average gas rates decreased below 90 per cent of the theoretical gas rates. With a feed rate of 0.26 g of propionic acid per day (Table I), the resulting gas rate was only 86 per cent of the theoretical rate. Feed rates of 0.342 g (as ammonium propionate) resulted in gas rates of 18 and 41 per cent of the theoretical rate, and feed rates of 0.776 g (as potassium propionate) resulted in gas rates of 16 and 37 per cent of the theoretical rate. This was true, although under these conditions gas rates were reached which temporarily exceeded the previously established optimum rates.

In Unit B2 an average gas rate of 220 ml per day was recorded for four days, and an average of 290 ml per day for three days at feed rates above the critical limit. These gas rates were,

TABLE III.—Butyric Acid

Unit No.	Days	Feed Rate, Avg (g/day)	Gas Rate, Avg (ml/day)	Per Cent of Theor. Gas Rate	Volatile Acids (ppm)	Substrate Used	Remarks
				(*a*) Series I			
3	6	1.221	1,340	99	1,038	*	—
C1	20	1.243	1,319	95	470	*	—
C2	10	1.248	1,417	102	610 to 1,960	*	Some excess gas from seeding material
3	7	1.628	1,654	92	1,320	*	—
C1	5	1.664	1,766	95	—	*	Optimum rate
C2	4	1.664	1,735	94	—	*	Optimum rate
				(*b*) Series II			
3	11	(3.256)	272	—	5,770	*	High volatile acids, due to previous overloading with two doses of 3.256 g of pure acid
C1	13	3.10	1,934	56	780 to 9,750	†	Unstable maximum rate, overloading conditions
C2	13	3.472	2,410	62	420 to 8,550	†	Unstable maximum rate, overloading conditions
C1	5	(5.96)	526	—	9,750	†	After overloading by single dose
C2	3	(5.96)	686	—	11,700 to 14,200	†	After overloading by single dose
C1	6	2.512	1,183	—	3,830 to 7,250	‡	Overloading
C2	6	2.512	345	12	6,150	‡	Overloading
C1	5	—	606	—	7,250	‡	After overloading by ammonium butyrate
C2	6	—	272	—	6,150	‡	After overloading by ammonium butyrate

* Butyric acid.
† Potassium butyrate.
‡ Ammonium butyrate.

however, not stable since they existed for only a limited time.

An accumulation of volatile acids took place in the units because not all of the acid added was converted to gas. When this accumulation of volatile acids was carried far enough, the gas rates decreased not only below the theoretical rate, but also below the optimum level. At a level of 2,640 to 2,860 ppm volatile acids, 62 and 140 ml of gas per day, respectively, were recorded in the presence of ammonium propionate. At a level of 4,430 to 5,400 ppm volatile acids, 110 and 125 ml of gas per day, respectively, were measured in the presence of potassium propionate. These gas rates represent from 30 to 62 per cent of the optimum rate.

The depression in the gas production could not have been due to a previous decrease in the activity of the methane bacteria, as the cultures were fully active at the time the increase in volatile acids concentration took place. Thus the inhibition of gas production must have been the result of the high volatile acids concentration as such. Interference by virtue of a drop in the pH value was also discounted because, in the case of the ammonium and potassium compounds, the pH stayed in a range of 7.2 to 7.8, even at the highest concentrations of volatile acids.

For acetic acid (Table II), the data show that, at feed rates beyond 1.0 g per day, the theoretical gas rates were not reached. Average optimum gas rates of 715 and 729 ml per day were recorded at feed rates of 0.894 to 0.934 g of acetic acid per day. Feed rates of 1.158 to 1.198 g per day resulted in gas rates measuring 69 to 82 per cent of the theoretical rates. At a feed rate of 1.608 g of acetic acid per day (as potassium acetate) only 41 per cent of the theoretical gas rate was realized. Accordingly, in all these cases the volatile acids concentration in the units increased from day to day.

During these periods of increasing volatile acids concentration, temporary maximum gas rates of 794 to 798 ml per day were recorded. However, when the volatile acids concentration exceeded 3,000 ppm, the gas rates not only were below the theoretical rates but also below the optimum rates. At volatile acids concentrations from 2,200 to 7,400 ppm, gas rates were 74 to 81 per cent of the optimum rate. These were the gas rates measured when potassium acetate was used. With ammonium acetate the reduction of the gas rates was even more pronounced. At 2,700 to 3,200 ppm volatile acids, only 25 to 42 per cent of the optimum gas rate was recorded. An increase of the volatile acids concentration to 6,320 ppm by overloading with pure acetic acid reduced the gas rate to 23 per cent of the optimum gas rate.

The average optimum gas rates for butyric acid (Table III) were 1,735 and 1,766 ml per day, which represented 94 to 95 per cent of the theoretical gas rate at a feed rate of 1.664 g of butyric acid per day. At feed rates of 3.10 and 3.472 g of butyric acid (as potassium butyrate) only 56 and 62 per cent of the theoretical gas rates were reached. Overloading by ammonium butyrate at feed rates of 1.675 and 2.512 g butyric acid per day produced gas rates of from 18 to 42 per cent of the theoretical values.

In the case of potassium butyrate feeding, high volatile acids concentrations had to be reached before the gas rates decreased below the optimum level. At volatile acids concentrations of 8,000 and 9,000 ppm, unstable maximum gas rates of 1,934 and 2,410 ml per day were recorded. At volatile acids concentrations from 9,750 to 14,200 ppm, the gas rate decreased to 30 and 39 per cent, respectively, of the optimum gas rate. With ammonium butyrate feeding, a range of 6,000 to 7,000 ppm of volatile acids was sufficient to reduce the average gas rate to 20 per cent of the optimum gas rate.

Summary and Discussion

Generally for all three organic acids, the same relationship between volatile acids concentration and gas production tended to appear. Independent of the pH value, gas rates decreased below the optimum level for all cases in which the volatile acids concentration had increased beyond a critical level.

These findings are at variance with the views of Golueke, Oswald, and Gotaas (4) as stated in their discussion of the anaerobic digestion of algae. According to their experiences the addition of volatile fatty acids up to a concentration of 4,500 ppm increased gas production proportionate to the acid dosage. They conclude, therefore, that any inhibiting effect of a high volatile acids concentration would be indirect, for instance by lowering the pH to undesirable levels.

The experiments reported herein show that, even at pH ranges from 7.2 to 7.8, an increase in the volatile acids concentration beyond a critical limit resulted in an impaired gas production. The absolute value of the critical limit varied considerably according to conditions. In the presence of ammonium ions a volatile acids concentration of 2,000 to 3,000 ppm was definitely inhibiting. In the presence of potassium ions, gas production was impaired at volatile acids concentrations from 2,200

to 7,400 ppm for acetate acid and propionate acid as feed. With butyrate feeding, higher volatile acids concentrations were tolerated. Even then gas production decreased to 30 and 39 per cent of the optimum rate at volatile acids concentrations ranging from 9,750 to 14,000 ppm. Apparently ammonia has an inhibiting effect of its own, which would combine with the effect of the volatile acids concentration. This is in agreement with the detrimental action of ammonia in the form of ammonium carbonate which has been reported by Snell (5).

Volatile acids concentration should not be considered as an isolated factor, since it is greatly influenced by other factors such as pH and cations present. Nevertheless, the fact that methane production ceased in all batch experiments containing more than 10 per cent raw sludge solids (Part I of this paper) is best explained by the excessive accumulation of volatile acids and their inhibitive action as such. Changes in pH or in ion concentration did not appear to be of equal importance in these cases. In addition, it should be noted that in all of the experiments where the feed rate was kept in balance with the capacity of the units (Tables I, II, and III), the volatile acids concentration did not increase beyond 3,000 ppm. In agreement with Buswell's observation (6) any volatile acids concentration above 3,000 ppm should therefore be considered as indicative of overloading. The fact that occasionally gas rates above the optimum level were recorded at higher volatile acids concentrations does not invalidate this criterion. These maximum rates were unstable and lasted only for a limited time. Continued accumulation of volatile acids always resulted in a severe depression of the gas production.

The experimental results agree with the general concept, that anaerobic digestion consists of a balanced process, where the raw material is continually broken down to organic acids by one group of microorganisms, and the organic acids in turn are converted to methane and carbon dioxide by a second group of microorganisms, the methane bacteria. The balance is kept in favor of methane fermentation by maintaining proper temperature, pH, and controlled feed rates. Maintenance of controlled feed rates appears to be the most important factor. Not only is the capacity of methane fermentation limited in a general way, but also with respect to different substrates.

Under the conditions described herein, a maximum of about 0.2 g of propionic acid or 1.0 g of acetic acid or 1.6 g of butyric acid was quantitatively converted to gas by 1 l of active digester volume per day. Higher feed rates regularly resulted in the accumulation of volatile acids and a depression of gas production. According to the results reported in Part I of this paper (1) the acid producers appear to be much less sensitive than the methane bacteria. They are not as easily affected by variations in moisture, temperature, or pH, or by an accumulation of their own metabolic products. Consequently acid production becomes the predominant process whenever adverse conditions occur, and especially when organic matter is present in a concentrated form. Mere buffering of the acids does not restore the activity of the methane bacteria. The use of KOH as a neutralizing agent would increase the tolerance of the methane bacteria and might be helpful in overcoming a lagging digester. For continuous operation the concept of a critical volatile acids concentration at about 3,000 ppm seems to be valid.

Acknowledgment

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ROBERT A. CANHAM JOINS FEDERATION STAFF

On October 1, 1957 Mr. Robert A. Canham became a member of the Federation headquarters staff. He will serve as Associate Editor of SEWAGE AND INDUSTRIAL WASTES.

Mr. Canham is a native of Illinois where his early years were spent. His professional training includes a degree of Bachelor of Science in Civil Engineering from Purdue University in 1942 and a Master of Science in Civil Engineering with Sanitary Engineering option from the same University in 1947. He is a registered professional engineer in Indiana. During the second World War he served two years in the commissioned reserve of the Navy.

His professional organization memberships include Associate Membership in the American Society of Civil Engineers and membership in the Virginia Industrial Wastes and Sewage Works Association.

For approximately ten years before joining the Federation staff, Mr. Canham served as Sanitary Engineer of the National Canners Association in Washington, D. C. His work with the research laboratories of this Association dealt with the development and improvement of methods of handling wastes from the food canning industry.

Since its inception he has served as a member of the National Technical Task Committee on Industrial Wastes as the representative of the canning industry. For several years he has been associated with the work of the Interstate Commission of the Potomac River Basin through membership on its Advisory Committee on Industrial Wastes.

Mr. Canham's service with the Federation will make available an engineer with thorough technical training and thoroughly qualifying experience with a specialty in industrial wastes. He is the author of numerous technical articles dealing with the treatment and disposal of food wastes. These have been published in this Journal as well as in other periodicals in the field of sanitary engineering.

Industrial Wastes

FOUL CONDENSATE TREATMENT AND DISPOSAL *

OIL REFINING INDUSTRY ACTION COMMITTEE OF THE OHIO RIVER VALLEY WATER SANITATION COMMISSION

Cincinnati, Ohio

FOREWORD AND ACKNOWLEDGMENT

Control of industrial waste discharges to prevent the impairment of water resources is one of the major tasks with which the Ohio River Valley Water Sanitation Commission is concerned. In this effort the eight-state agency—representing Illinois, Indiana, Ohio, Pennsylvania, New York, Virginia, West Virginia and Kentucky—has invited the participation of advisory committees representing generic industry groups. One of these, the Oil Refining Industry Action Committee, recently completed an appraisal of the problem of handling foul condensate water. This problem is considered to be one of the three most urgent matters before the committee; the others are oil separation and spent caustics.

Findings of this expert group were submitted to the Commission for use among its member states and for refinery operators within the states. However, release of the report for general publication is not to be construed necessarily as Commission endorsement of any views expressed.

The commissioners of ORSANCO acknowledge with appreciation the efforts of the Oil Refinery Industry Committee, presently under the chairmanship of Mr. M. W. Nicholas, staff manager, Ohio Oil Company, in developing this report. In particular, the Commission recognized the work of the subcommittee consisting of Chairman L. H. Corn, Gulf Oil Corporation; D. T. Quinn, Socony-Mobil Oil Company; and O. J. Zandonna, Ashland Oil and Refining Company.

EDWARD J. CLEARY
Executive Director and
Chief Engineer, ORSANCO

A survey of petroleum refineries in the Ohio River Basin by the Waste Treatment Methods Subcommittee revealed that spent caustic, oils in water, and waste water such as foul condensate constitute the most difficult waste disposal problems for the refineries. Reports entitled "Disposal of Spent Caustic Solutions" and "Reducing the Oil Content of Refinery Waste Waters" have already been presented to and approved by the Oil Refining Industry Action Committee. Pursuant to the above survey the companies indicating problems in foul condensate treatment were requested to submit summaries of their experiences. Information from these summaries and from private correspondence constitute the basis for this report.

The Problem

Water in contact with oil absorbs some of the oil and even more of other constituents which may be present. Thus water entering the oil stream as stripping steam, wash water, inad-

* Approved for publication by the Ohio River Valley Water Sanitation Commission, October 1, 1957.

vertently by leakage, or otherwise, collects in reflux drums or other accumulators and must be withdrawn, usually continuously. Thus from a catalytic cracking unit where ammonia compounds, phenolic type compounds, and hydrogen sulfide are present along with steam, the resulting condensate is a foul waste water. Under some conditions this water can be diluted and rejected to the waste water system, but in many instances some treatment is required before disposal.

The Objective

It is the objective of this report to make known the experiences of some refiners who have solved this problem to other refiners who must face the same or related problems. It is hoped that this report will supply enough information for a refiner to take corrective measures if his problem is similar to those covered here.

Disposal Without Treatment

Where a refiner has a waste water disposal problem, isolation at the source and reuse or treatment before dilution is advised. The reuse of this foul condensate, then, is a method of disposal without treatment. Dilution is a satisfactory disposal method when the effluent requirements can be met.

Since the type of refinery specifically referred to here is one with desalter, atmospheric-vacuum crude distillation, fluid type catalytic cracking, reforming, gas recovery, alkylation and polymerization units for gasoline production, there are certain general statements which can be made. Thus from the main fractionator on the cracking unit, the gas recovery reflux drums, and the interstage compressor knockout drums foul condensate is collected. On this same type cracking unit, spray water is required for the regenerator to control temperatures and to prevent afterburning in the equipment. The use of the foul condensate water as spray water has proven successful for some operators yet others have met insurmountable difficulties in this application. A principal shortcoming of this method of disposal is the fact that the rate of production of condensate may exceed the spray water requirements so that other reuse or treatment must be found.

A major difficulty experienced in the use of foul condensate as spray water has been the plugging of spray nozzles. Since raw foul condensate is essentially colorless and low in turbidity any deposit that occurs must be formed in the spray water system. The deposits have variously been considered to be: (a) the reaction product of hydrogen sulfide attack on the metals of the spray water lines, (b) the products of oxidation reactions on contact with air, and (c) the product of chemical reaction of foul condensate components upon heating. While spray water systems in general appear to be constructed of plain carbon steel, consideration is usually given to the other two factors. In most successful installations the foul condensate in the spray water system charge drum is blanketed with steam to avoid contact with air. Further, in the successful installations the foul condensate spray water is injected into the regenerator and/or flue gas lines without preheating.

A summary of the experiences of one installation using foul condensate as normal spray water to the regenerator is shown in Table I.

Samples of the deposits in the spray nozzles were found to contain considerable copper. The condensate from the high-pressure separator also was found to contain copper in concentrations as high as 186 ppm. The high-pressure separator condensate was therefore segregated from the rest of the foul condensate and was routed directly to a sewer since equipment limitations would not permit separate handling for charging to the stripper tower. On a subsequent run the sprays operated 16, and later more than 21,

days before plugging. The use of a film-forming organic amine corrosion inhibitor to reduce corrosion of the admiralty metal tubes in the condensers ahead of the high-pressure separator was effective in prolonging bundle life, but gave no significant relief from spray nozzle plugging. Routing of the high-pressure separator condensate directly to the sewer could not be tolerated longer than for a trial run period; therefore the use of foul condensate as normal spray water has been discontinued at this installation, and stripping treatment is being used.

Treating Technique

When no reuse of the foul condensate is found, it is suggested that stripping be the first step in treatment. The water varies in properties due to the contaminants. With a pH range of 8.3 to 9.3, ammonia as much as 4,000 ppm, phenolics to 1,000 ppm, and hydrogen sulfide from 350 to 8,000 ppm, the stripping action can be used to reduce the ammonia and hydrogen sulfide for elimination from the system.

For this type installation, the foul condensate amounts to some 2 gpm for each 1,000 bbl per day of cracking unit capacity. This varies widely and can to some extent be controlled. Thus strippers are in use on such units with capacities in the range of 25 to 110 gpm. The basic equipment for such an installation consists of an accumulator, a charge pump, a heat exchanger, a stripper tower, and instruments as required.

The stripping medium can be flue gas, steam, air, or a combination of these. With the fluid catalytic cracking unit where the flue gas is under some 5 psig pressure, the use of flue gas is suggested. Steam for additional stripping and in particular to control temperatures is advisable. The off gas may go to a furnace or be vented into other flue gases.

The raw foul condensate is usually routed through the shell side of exchangers and steam heaters to retard plugging. Acid injection was formerly used to increase the hydrogen ion concentration so as to shift the equilibrium reaction toward evolution of hydrogen sulfide. Subsequent experience demonstrated that temperature control by steam rate regulation is sufficient to obtain good stripping without requiring pH adjustment.

Baffle plates, bubble cap trays, and packed towers have been used successfully for strippers. One unit operating at a foul condensate charge rate of 100 gpm obtains 97 per cent reduction in hydrogen sulfide and 66 per cent reduction in ammonia content, using steam stripping in a 5-ft diameter tower containing 6 bubble cap trays. Another unit charging 40 gpm obtains

TABLE I.—Operating Data from Foul Condensate Use as Normal Spray Water to Regenerator

Run No.	Protection of Foul Cond. from Air	Preheating of Foul Cond. Water Spray	Nozzle Opening		Screen Perforations (in.)	Steam Dispersal of Spay Water	Operation Without Nozzle Plugging (days)	Screens Plugged
			Water* (in.)	Steam (in.)				
1	No	Yes	0.07†	$1\frac{7}{8} \times \frac{3}{16}$	$\frac{3}{64}$	Yes	3.2	No record
2	Yes	No	0.07†	$1\frac{7}{8} \times \frac{3}{16}$	$\frac{3}{64}$	Yes	1	No record
3	Yes	No	0.11†	$1\frac{1}{4} \times \frac{3}{16}$	$\frac{3}{64}$	Yes	1	No record
4	Yes	No	0.16†	$1\frac{1}{4} \times \frac{3}{16}$	$\frac{3}{64}$	Yes	12	No
5	No	No	0.22‡	$1\frac{1}{8} \times \frac{3}{16}$	$\frac{3}{64}$	Yes	16 & 21	No record

* Spray water rate—13 gpm; foul condensate is 35 per cent of spray water; spray water injected at normal spray water point to the regenerator; temperatures of 1,000 to 1,100° F at injection points.

† Two openings.

‡ Two openings made into one by a $\frac{3}{32}$-in. wide connecting slot.

TABLE II.—Results of Stripping Foul Water Condensate for Hydrogen Sulfide Removal

Run No.*	Steam Rate per Gal of Charge (lb)	Stripping Temp. (° F)	pH		H_2S (ppm)		H_2S Reduction (%)
			In	Out	In	Out	
1	0.62	160	8.3	9.5	680	119	82
2	0.62	160	—	—	2,169	141	93
3	0.73	160	—	—	2,550	2,550	0
4	0.67	160	—	—	2,380	1,950	18
5	0.67	160	—	—	2,640	2,220	16
6	1.15	200	—	9.3	2,630	51	98
7	1.07	200	9.2	9.8	1,210	68	94
8	1.07	200	9.2	9.9	1,844	34	98

* Charge rate of 35 to 40 gpm; exhaust steam as stripping media; atmospheric tower pressure; no acid injection.

95 per cent reduction in hydrogen sulfide using steam stripping in a 30-in. tower containing 24 center to side baffles.

The operating conditions and results over a two year period for one unit are reported in Table II.

These data demonstrate that a minimum stripping temperature of 200°F is required to obtain dependably effective results. Maintenance and operating cost reports indicate that operation at high temperatures is more economical and dependable than operation at low pH values. Therefore, the most satisfactory operating conditions for stripping foul condensate appears to be as follows:

1. Stripping temperature: 200°F minimum.
2. Stripping media: exhaust steam @ 1.1 lb per gal of charge.
3. Stripping pressure: minimum required to maintain the water in a liquid state.

Feed preheating is desirable since it reduces the tendency for the fresh charge entering the tower to absorb hydrogen sulfide which has been stripped out in the lower section of the unit. Preheating also reduces the amount of steam required to obtain the desired operating temperature of 200°F. No data are available to indicate the effectiveness of flue gas stripping at high temperatures. However, it can be surmised that this practice would be effective if flue gas were used in sufficient quantity and with preheating to 200°F.

Table III represents data from another installation showing the typical analyses of the foul condensate on three separate days.

The data in Table IV are presented to show ranges of plant operation. No pH control was used. The pH can be regulated by the degree of ammonia stripping which in turn is done by adjusting the operating temperature and ratio of flue gas to water.

Disposal of the Condensate After Flue Gas Stripping

One of the most promising methods of disposal of the condensate and the removal of phenols is by reuse as de-

TABLE III.—Typical Constituent Analyses of Foul Condensate

Item	Date		
	Nov. 14, 1950	July 26, 1954	Jan. 4, 1955
pH	8.4	8.7	8.7
Total solids (ppm)	140	95	47
Sulfide sulfur (ppm)	5,900	4,300	3,750
Phenolic type compounds (ppm)	515	976	530
Ammonia (ppm)	4,000	4,100	2,700
Oil (ppm)	261	—	—
Oxygen consumed by permanganate (ppm)	784	—	—

TABLE IV.—Operational Data for Flue Gas Stripping of Foul Water Condensate

Item	Operator Number					
	1*	2	3	4	5	6
Flue gas to water ratio (cu ft/gal)	31.9	34.4	33.8	18.4	18.4	0
Steam to water ratio (lb/gal)	0	0	0.45	0	0.21	0.21
Decrease in sulfide sulfur (%)	82.3	100.0	100.0	100.0	100.0	100.0
Ammonia removed (% by wt)	52.8	63.1	62.7	48.4	54.8	30.0
(*a*) Analysis of Treated Condensate						
pH	8.7	8.3	7.7	8.9	9.0	9.3
Sulfide sulfur (ppm)	1,070	nil	nil	nil	nil	nil
Ammonia (ppm)	2,060	1,800	1,750	2,300	2,000	2,900
Total solids (ppm)	1,026	2,475	3,586	716	681	469
(*b*) Temperature (°F)						
In	400	460	460	443	443	—
Out	168	166	175	175	179	199
(*c*) Pressure (psig)						
Flue gas in	4	4	4	4	4	—
Degassing drum	2	1.3	1.4	1	1	—

* Stripping section contains baffles for this operation only.

salter water. Controlled pH will permit operating units downstream with the desired pH of subsequent condensate streams. In fact, the requirements of ammonia for pH control have been reduced by the control of the amount of ammonia stripping.

In mixing condensate with other streams plugging often occurs. This can be eliminated by reusing water and not mixing with extraneous water. Thus the condensate from vacuum tower surface condensers and atmospheric overhead condensers can be reused along with the stripped water.

The data from one existing unit shows that an electric desalter removes some 95 per cent of the phenolics from water charged to them. However, some 10 to 15 per cent of this water shows up in subsequent streams for a net removal of 80 to 85 per cent. By recirculation of the atmospheric overhead condensate, a removal of approximately 90 per cent is obtained.

The question of injecting the cracking still condensate directly into a desalter often arises. If it is low enough in hydrogen sulfide and if the pH can be controlled, it is possible to eliminate the flue gas stripping.

Summary

The direct disposal of foul condensate without treatment has been attempted at one installation by using the foul condensate as normal spray water to the fluid catalytic cracking unit regenerator to control afterburning. While this method may not dispose of all of the foul condensate produced from a unit, it offers a means of reducing the load on the foul condensate stripper and may in turn permit more effective stripper operation. Additional information on this method of disposal is desirable in order to determine the basic principles which must be observed and to determine the de-

pendability and the usefulness of the method.

A reasonably effective, economical, and dependable method of treating foul condensate by stripping to reduce the hydrogen sulfide content has been developed. The process, which obtains better than 95 per cent hydrogen sulfide reduction, appears to function most effectively at low pressure, at temperatures in excess of 200°F, and at a minimum stripping steam rate of 1.1 lb of steam per gallon of charge. The process is reasonably free from corrosion and fouling problems. The reduction of sulfides by air oxidation (1) is also a consideration.

Reuse of the stripped water in a desalter has aided in reducing the phenolics although biological oxidation may be necessary for a final reduction (2). Other reuses are recommended for future study.

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2. Elkin, H. F., "Biological Oxidation and Reuse of Refinery Waste Water for Pollution Control and Water Conservation." Amer. Petroleum Inst. Div. Refining Midyear Meeting (May 1956).

MEETINGS OF INTEREST

1958

Feb. 26–28	**American Society of Civil Engineers,** Sherman Hotel, Chicago, Ill. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.
Mar. 4	**Great Plains Sewage Treatment Plant Design Conference,** Castle Hotel, Omaha, Nebr. V. J. Lechtenberg, 614 Standard Oil Building, Omaha, Nebr.
Mar. 17–21	**Fourth Nuclear Engineering and Science Conference,** International Amphitheatre, Chicago, Ill. (See page 198.)
Mar. 27–28	**Seventh Southern Municipal and Industrial Waste Conference,** Duke University, Department of Civil Engineering, Durham, N. C.
Apr. 11.	**Industrial Wastes Conference,** Georgia Institute of Technology, Atlanta, Ga. Water Quality Division, Georgia Department of Public Health, 309 State Office Bldg., Atlanta 3, Ga.
Apr. 18	**Annual Pennsylvania Clean Streams Conference,** Penn-Harris Hotel, Harrisburg, Pa. Pennsylvania State Chamber of Commerce, Harrisburg, Pa.
Apr. 20–25	**American Water Works Association,** Dallas, Texas. Harry E. Jordan, Secretary, AWWA, 2 Park Ave., New York 16, N. Y.
May 5–7	**Thirteenth Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University, Lafayette, Ind.

PHENOL RECOVERY BY USE OF ISOPROPYL ETHER*

By Norbert H. Kirchgessner

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The recovery of phenol from waste water has long been considered the most serious water pollution problem in the plastics industry. Earlier work (1) discussed briefly the wide variety of waste problems encountered in a fully integrated manufacturing plant producing phenolic resins and molding compound. One of the most important of the many problems discussed was the recovery of phenol and other phenolic materials from the distillates produced in the manufacture of phenolic resins.

Source of Phenol Distillates

In the commercial manufacture of resins from phenol and formaldehyde the reaction is never completely quantitative. As a result, during the dehydration stage phenol and formaldehyde are distilled off with the water from the formaldehyde solution and the water resulting from the condensation reaction. The water solution has a phenol content which varies from 4 to 6 per cent in any plant which produces a variety of phenolic resins. The free formaldehyde content varies widely and is dependent upon the techniques used in the resin manufacturing process. Concentrations vary from 0 to 5 per cent. In production the high formaldehyde concentrations obviously result in low yields of resin. At the same time recovery is seriously complicated by the tendency of the phenol and formaldehyde to react during the recovery process. At the high limit of the formaldehyde concentration one German plant (2) has found it practical to conduct a second condensation under alkaline conditions. The resin thus formed is precipitated and recovered as a salable product.

The recovery problem is also complicated by the presence of cresols and other phenolic materials used in resin manufacture. The vacuum dehydration processes used also result in the distillation of phenol alcohol and low molecular weight resins. In addition, the phenol and formaldehyde which are withdrawn continue to react to some extent in the presence of catalysts which may be in the distillate. No detailed study has been made at any time to obtain a complete analysis of the distillates, since the phenolic components are recovered under practically the same conditions as phenol.

Background

When the original phenol recovery plant was designed for the North Tonawanda plant the International Joint Commission had not yet started surveys on the boundary waters which eventually resulted in the issuance of "Objectives." The New York State Water Pollution Control Board was still a dream which existed only in the minds of a small group in the New York State Legislature and Department of Health. Since there were no legal objectives, the plant was designed on the basis of sound economics only and the effluent was standardized at 500 ppm phenol. Except for short pe-

* Presented at 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

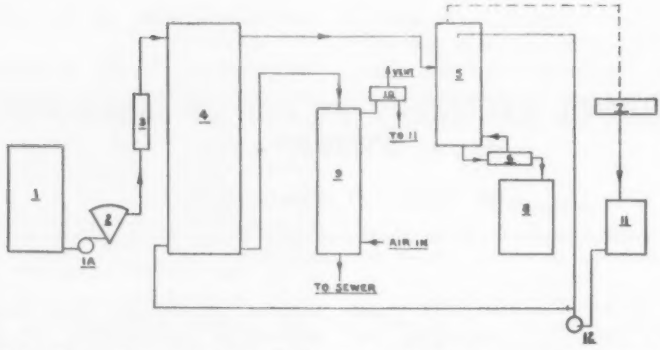

FIGURE 1.—Flow diagram of phenol recovery system by benzene extraction showing:

1. Distillate storage tank.
1A. Feed pump.
2. Filter.
3. Feed water preheater.
4. Extraction column.
5. Distillation column.
6. Reboiler.
7. Condenser.
8. Phenol storage tank.
9. Benzene stripping column.
10. Helical condenser.
11. Benzene storage tank.
12. Benzene pump.

riods of time this result was never obtained under normal operating conditions because of the speed with which the equipment became fouled with resin. A simplified flow sheet for the original unit is shown in Figure 1.

As originally conceived and operated this was a simple countercurrent extraction of the phenol distillates with benzene. Unfortunately, the extraction of the phenol from the water so reduced the solubility of the resin present that precipitation occurred in the column and resulted in severe channelling. Efficiencies dropped to very low levels and it became necessary to change the Raschig ring packing at frequent intervals.

In an attempt to solve this problem and simultaneously increase the extraction efficiency a second column was installed in series with the original column. The first column was packed with 2-in. rings and became, in effect, a combination extraction column and filter. The large rings provided space for the resin deposit without causing the liquids to channel. As with all temporary expedients this adaption helped some but only extended the period during which efficient operation could be maintained instead of correcting the underlying cause of the trouble. A larger holding tank also helped to improve conditions but results were still not adequate on a long term basis.

Since past and present experience reveal the requirements for better recovery efficiencies, a search has been started to find a solvent that would make this possible. Prevailing economics set the policy that the existing equipment should be used with as little change as possible. This automatically eliminated the use of any high boiling solvents. Heller (3) has outlined in great detail the factors which must be considered in the selection of a solvent for a process of this type.

Choice of Solvent

For the process under consideration it was not practical to use light oil, tricresyl phosphate, or any of the proprietary solvents due to high boiling ranges. It also was not desirable to modify the process in any direction that required caustic for solvent regeneration. The possibilities of springing phenolate and subsequent solvent

recovery were not considered to be practical for the volume under study.

A preliminary search of the literature indicated that isopropyl ether offered considerable promise. Continuation of the search showed that this material had been used with considerable success (4) at a coal-hydrogenation installation. The coal operation was, however, somewhat different because of the absence of thermosetting resinous material, always present in the plastics feed stock under study. Also conditions of use and design permitted a relatively large excess of solvent to be used at the coal location. Because of the original basic design it was not possible to use an excess of solvent in the plastics plant.

The initial laboratory experiments using isopropyl ether were encouraging. Equilibrium distribution studies showed approximately the same results as had been obtained by Edmonds and Jenkins (4). These results are shown in Figure 2. The difference in the curves is to be expected since the original data reflected the use of pure phenol while the present data was obtained on a typical phenol distillate used as feed stock for the operating unit.

Analytical Method

For all work reported in this study Scott's bromination procedure (5) for the determination of phenols was used. This is a routine method of analysis at

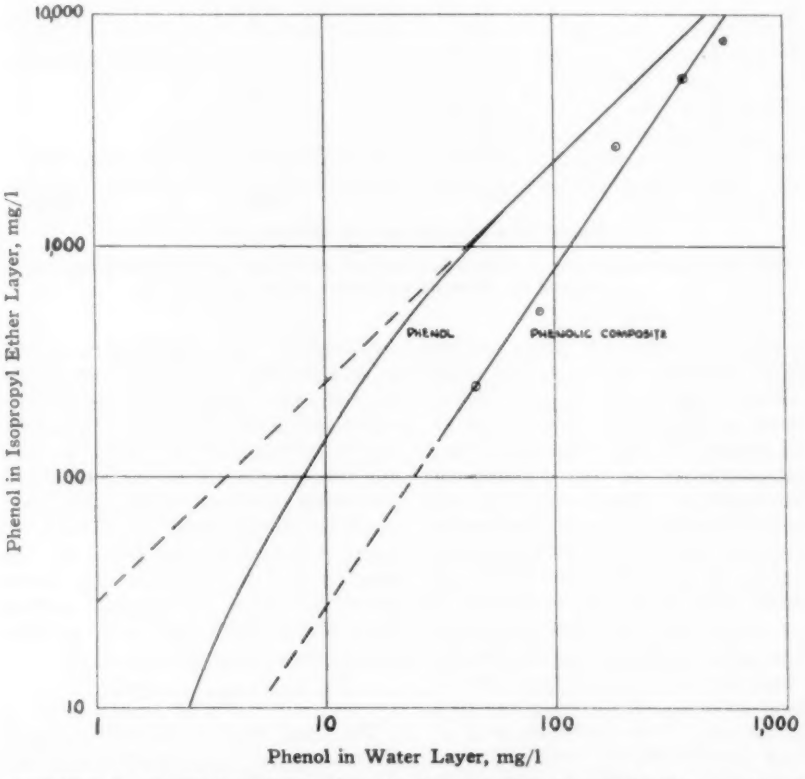

FIGURE 2.—Equilibrium distribution showing phenol in isopropyl ether *vs.* phenol in water.

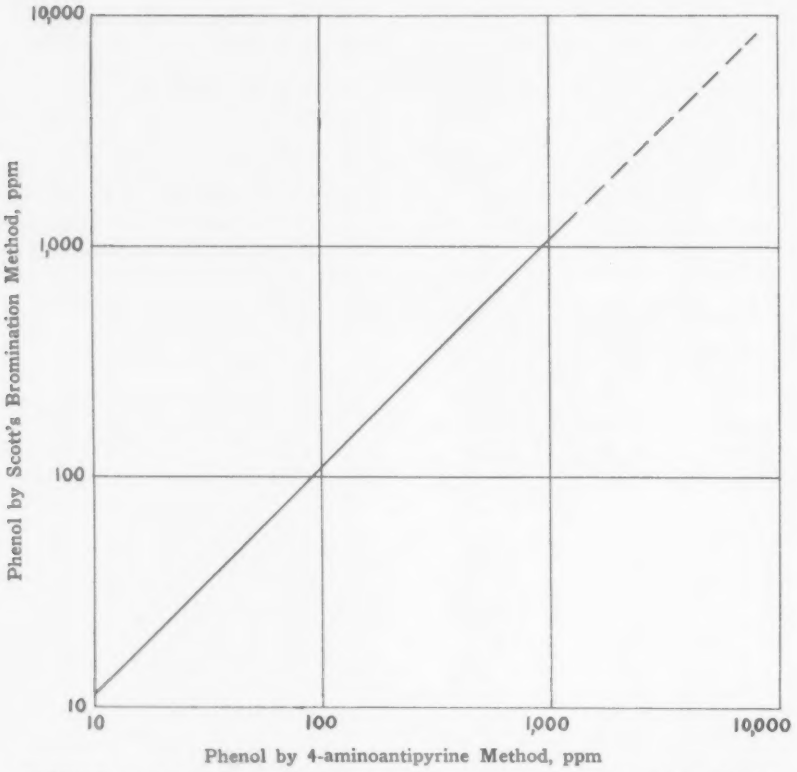

FIGURE . —Comparison of Scott's bromination procedure and 4-aminoantipyrine method for phenolic equivalent of wastes.

the plastics production plant and no special training or equipment is needed to obtain satisfactory results. Figure 3 shows a correlation between the results obtained by the bromination and results obtained by the 4-aminoantipyrine method. Black *et al.* (6) has also given results on coke plant wastes indicating that if proper precautions are taken in the analysis and reasonable care is used in the interpretation of the resultant data, the bromination procedure gives results of considerable usefulness for all but the most fundamental studies. One feeling has been that because of the technical skill required for the Gibbs method it was not practical at higher concentrations where great precision was not required. Although the 4-aminoantipyrine method is considerably easier than the Gibbs method, the former still determines cresol and a variety of other phenolic compounds similar to phenol in taste and odor-producing properties. When concentrations drop below 1 ppm either the Gibbs or the 4-aminoantipyrine becomes necessary. However, for the gross phenol measured in the Durez plant, the Scott bromination method gives results which can easily be compared among themselves.

Safety

The final decision to use isopropyl ether was made only after careful consideration of the safety problems associated with its use. This was not an

easy decision to make in a plant where ether odors traditionally have been considered to originate in the laboratory or in a first aid room. According to the literature (7) isopropyl ether forms explosive compounds of uncertain composition and constitution. It is generally believed that the peroxide does not accumulate in high concentration but rather decomposes in the presence of water to form hydrogen peroxide, acetone, and isopropyl alcohol. A serious psychological problem developed when the traces of ether normally present were first detected by plant personnel. However, in the long run, the uncertainty has contributed considerably to the safety consciousness of plant personnel. It is interesting to note that after a full year of operation no trace of peroxide has ever been detected in the daily sample sent for analysis to the plant laboratory.

Process

Figure 4 shows the simplified flow diagram for the plant as it is now being operated with the ether solvent. The distillate storage tank serves the dual purpose of storage and at the same time a surge to level out fluctuations in volume and concentration caused by variations in resin production. A small tank at each of the production units collects the distillate for automatic pumping to the main storage tank. The first column is 3 ft in diameter and is packed with 30 ft of 2-in. Raschig rings. This serves as a combination extraction column and filter and permits resin to accumulate where the efficiency of the process will be least affected. The second column is 3 ft, 6 in. in diameter and is packed with 30 ft of 1-in. Raschig rings. Distillates are fed in series through the columns and ether flow is countercurrent.

The water raffinate is saturated with ether and since the solubility under the existing conditions of operation is approximately 1 per cent it is necessary to strip the ether from the water. This operation is performed in the small ether recovery column. As a steam

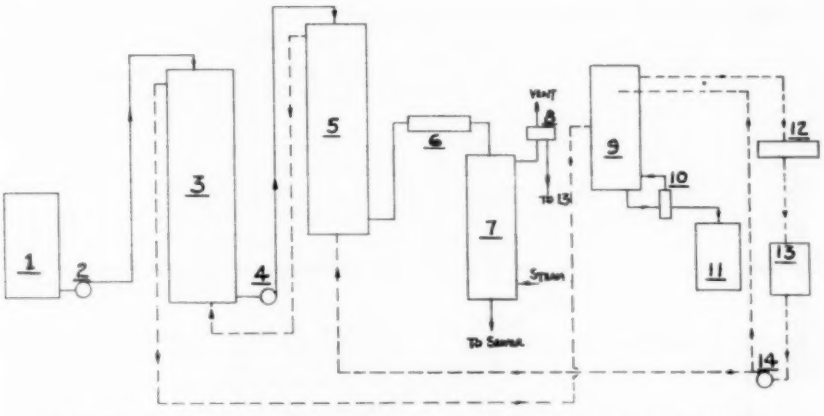

FIGURE 4.—Flow diagram of phenol recovery by ether extraction showing:

1. Distillate storage tank.
2. Pump.
3. Extraction column.
4. Pump.
5. Extraction column.
6. Water heater.
7. Ether recovery column.
8. Condenser.
9. Distillation column.
10. Reboiler.
11. Phenol storage tank.
12. Condenser.
13. Ether storage tank.
14. Pump.

TABLE I.—Results of Operating Tests of Phenol Recovery by Isopropyl Ether

Test No.	Flow Rate (gpm)		Ether to Water Ratio	Phenol (ppm)		
	Ether	Water		Water Feed	Waste to Sewer	Recirculated Ether
1	2.0	12.0	0.166	46,300	1,700	24
2	4.0	12.0	0.333	47,600	1,100	30
3	4.0	8.0	0.5	48,500	670	32
4	6.0	16.0	0.375	45,400	870	19
5	6.0	12.0	0.5	55,550	330	17
6	6.0	8.0	0.75	55,400	600	39

economy measure the water passes through a heater containing condensing ether from the distillation column as the heating medium. Waste flash steam from a nearby process is used to provide the necessary steam for the stripping operation. The ether-phenol mixture is sent to the fractionation column where the ether is recovered for recycling to the process. Phenol is sent to storage. This phenol contains all of the low volatile, ether soluble materials present in the original distillate and is carefully segregated from regular USP production.

Test Results

A typical analysis of phenol distillate waste from resin manufacturing shows the following characteristics:

1. A phenol weight of 5.0 per cent.
2. A free formaldehyde weight of less than 1 per cent.
3. A pH of 6.5.
4. A specific gravity of 1.02.
5. A non-volatile weight of less than 0.5 per cent.

The results of a series of tests covering the economic range of this unit are shown in Table I.

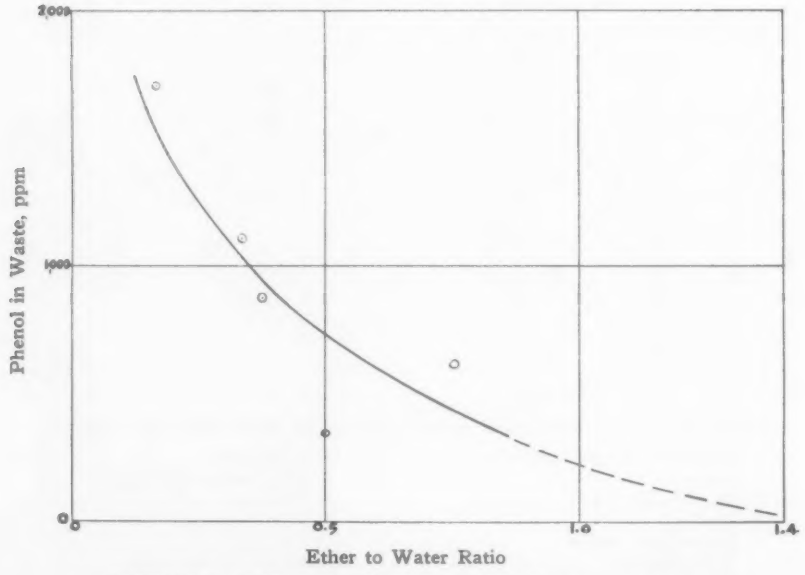

FIGURE 5.—Effluent phenol as a function of ether-water ratio.

Figure 5 shows some of these results in graphic form. As would be expected the phenol in the effluent decreased as the ether-water ratio increased. Normal operation in the resin plant has been at a ratio of 0.5 with a combined flow of 15 gpm. The resulting discharge has averaged 500 ppm or 60 lb of phenol a day. Better operation is obtained immediately after the system is cleaned. At this time the plant has averaged less than 200 ppm phenol in the discharge for a full week of operation.

Phenolic contents of this order of magnitude make it possible to discharge effluents directly into the city storm sewer leading to the receiving river. Since in the long run it is planned to concentrate and recover all phenol wastes through this system, considerable effort was and is being expended to improve the operation of the unit. It is known that a further phenolic reduction can be achieved if the pH of the wastes is adjusted prior to the extraction. It is estimated that such improvements would reduce the phenol discharged to less than 20 lb a day.

Economic Data

The items contributing to the principal operating costs of the recovery operation are as follows:

1. There are 4 lb of steam required for 1 lb of phenol recovered.
2. There are 0.03 lb of ether required for 1 lb of phenol recovered.
3. There is a labor requirement of half-time for 1 man.

It is interesting to note the increase in capital required to recover one pound of phenol as this process has advanced.

The initial single column unit using benzene as a solvent would cost $70,000 at today's prices. The addition of the second column and equipment to handle ether would cost $21,000. Additional equipment to control pH and settle the precipitated resin is estimated to cost $12,000. The capital investment to recover 1 lb of phenol a day is tabulated in Table II, and illustrates the high cost of recovering the last few pounds.

TABLE II.—Capital Costs for Phenol Recovery

Treatment Stage	Equipment Cost ($)	Phenol Recovered (lb per day)	Capital Investment Per Lb of Phenol Per Day ($)
1	70,000	5,700	12
2	21,000	240	88
3	12,000	40	300
Future	?	20	?

The question mark represents the answer management is interested in knowing more about and is a question which seriously affects plant location studies for any chemical producer using phenol. The cost of achieving absolutely zero phenol in a plant discharge is prohibitive, and where states impose this requirement a serious handicap is presented to any industry thus affected.

At the present time work and studies are in progress in many places on the odor- and taste-producing effects of phenolic materials. It appears that the present limits of 3–5 ppb, as the threshold of taste, are largely dependent upon the synergistic effects of other compounds in the presence of phenol. If the taste threshold limits can be increased it may be possible to continue to use the natural self-purifying capacity of streams without resort to uneconomic treatment methods.

Summary

The following represents a summary of the studies of phenol recovery by use of isopropyl ether:

1. The use of isopropyl ether for the recovery of phenol from phenol distillates has shown a substantial improvement over the use of benzene.
2. The process is potentially capable of producing an effluent containing less than 100 ppm of phenol. This would

permit treatment, after suitable dilution, by conventional sanitary sewage treatment plants without causing harmful effects on the biological flora of secondary treatment processes.

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NUCLEAR CONFERENCE WASTES SESSIONS

The Fourth Nuclear Engineering and Science Congress, March 17–21, 1958 (see p. 190), now has a final schedule for the waste treatment and disposal portion. Papers for the two sessions are listed as follows:

Tuesday Afternoon, March 18, 1958

"Treatment of Liquid Radioactive Wastes—European Practice," by C. P. Straub.

"Characteristics of Reactor Fuel Process Wastes," by J. O. Blomeke, E. D. Arnold, and A. T. Gresky.

"Studies on Characteristics of Savannah River Wastes," by B. Manowitz, C. W. Pierce, and S. Zwickler.

"Tracer Studies on Tidal Estuary Models," by P. J. Huiswaard, R. B. Banks, and C. G. Bell.

"Effects of Uranium Ore Refinery Wastes on Receiving Waters," by E. C. Tsivoglou, A. F. Bartsch, D. E. Rushing, and D. A. Holaday.

Wednesday Afternoon, March 19, 1958

"The Movement of Strontium-90, Cesium-137, and Plutonium-239 Through Tuff Local to the Los Alamos, New Mexico, Area," by C. W. Christenson, E. B. Fowler, G. L. Johnson, E. H. Rex, and F. A. Vigel.

"The Behavior of Ruthenium in the Fixation of Fission Products," by W. E. Erlebach and R. W. Durham.

"Treatment of Radioactive Wastes Using Ion Transfer Membranes: Removal of Bulk Electrolytes," by E. A. Mason, E. J. Parsi, and A. J. Giuffrida.

"Geological and Hydrologic Guides to the Ground Containment and Control of Wastes at Hanford," by R. E. Brown and W. H. Bierschenk.

"Radioactive Liquid Waste Disposal From the Dresden Nuclear Power Station," by C. F. Falk.

"The Effect of Radioactive Materials on Sludge Digestion," by W. N. Grune.

COMBINED TREATMENT OF INDUSTRIAL AND DOMESTIC WASTES *

By L. S. Kraus

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There have been recent contributions to the literature on the subject of combined industrial and municipal wastes (1) (2). Since this information is pertinent to other applications a brief summary of the conclusions of these studies appears herein. In the ORSANCO report (1) an analysis of a survey questionnaire of 100 treatment plants revealed the following:

1. That the industrial waste loadings received by these municipal plants represent about one-third of the total BOD and suspended solids, and one-fourth of the total flow being treated.

2. That 40 per cent of the plants prohibited explosive, toxic, or otherwise damaging substances from being discharged to the sewers, usually at the discretion of the sanitary engineer, and that 11 per cent placed numerical limits on certain specific substances.

3. That 49 per cent of the plants placed no restrictions on industrial waste discharge.

4. That 61 per cent of the plants reported operating troubles due to industrial wastes, and 17 per cent indicated that these troubles could not be solved at the treatment works.

5. That operating problems did not appear to reduce appreciably the efficiency of plants with secondary treatment.

Another report (2) presented the following considerations:

1. That combined treatment does not relieve industry of the responsibility for waste treatment.

2. That industry must eliminate wastes that can be removed at a cost less than their share of the cost of combined waste treatment.

3. That industry must be willing to pay its fair share of the cost of combined treatment.

4. That industry should make available to the municipality all information relative to the nature and quantity of its wastes.

5. That the municipality should treat all wastes that can be treated with greater economy in combined form than by industry alone at fair charges to the industry.

6. That the need for cordial cooperation and fairness from both industry and the municipality is essential to the success of combined treatment.

Nature of Industrial Wastes

Industrial wastes can be grouped into two broad divisions from the combined treatment viewpoint, those that are amenable and those that are not amenable. These may result both from continuous and batch processes. When a waste is not amenable its characteristics are such that there is substantial interference with the basic plant processes and not simply hydraulic overloading of the treatment works facilities. If toxic substances are present in an industrial waste in sufficient concentration to inhibit bacterial growth after dilution with the remaining wastes of the community, the waste is not amenable, since there would be interference with the biological processes at the treatment works. When an industrial waste is amenable it assumes that any existing overloading of the

* Presented at the 30th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Boston, Mass.; Oct. 7–10, 1957.

treatment works can be corrected simply by enlargement or modification of the treatment facilities. The ORSANCO report (1) indicates that wastes containing materials toxic to organisms and suspended objects, such as feathers which clog orifices and pipe lines, are not amenable. Wastes exhibiting pH extremes are considered amenable since the condition can be remedied either in the treatment works or at the industry.

Wastes that are not amenable must be kept out of the treatment works. Batch process amenable wastes can be converted easily to the equivalent of continuous process amenable wastes, when necessary, by equalizing tanks at the industry. Thus it is possible to consider all amenable wastes as being susceptible to treatment at the sewage treatment works without undue strain on its operators' equanimity.

There is no question about the effective treatment of amenable industrial wastes. The ORSANCO report (1) indicates that in only 11 of the 100 plants reporting could the difficulty encountered at the treatment works not be remedied. In Illinois, seven sanitary districts treat combined industrial and domestic wastes in complete treatment plants. The total population equivalent of these plants is about 9 million while their population is about 5 million. While these plants do not operate without problems, they do treat the combined wastes effectively. The treatment of 4 million population equivalent of industrial wastes of many types is adequate evidence that the procedure is a sound one.

Recommendations for Industry Only

Industry should include waste treatment costs in each process balance sheet. Too often this cost is not properly considered in evaluating the economics of a process. Frequently there can be justification for recovery and reuse of waste products if the cost of waste treatment is deducted from their recovery cost. It is not improbable that a process may be completely uneconomical if the cost of waste treatment is included.

When a new process is considered in which wastes are to be treated industry should evaluate the waste problem before the process is put into operation. Where waste treatment is an uncertainty, industry should include waste disposal studies in the process pilot or development studies.

Industry should advise regulatory agencies and local treatment works as to the nature of its waste problem so that adequate preparation for the treatment of the wastes may be made.

Just as industry has quality control for its production, so should it provide waste control for its process losses. In many cases a responsible waste control agency can cut production costs and ease waste treatment problems.

Industry should keep in mind that waste treatment is as much a part of its processes as is the power plant or the water supply.

Industry should be as cooperative as possible with regulatory and local treatment works agencies so that its problems may be few and its profits large.

Recommendations for Municipalities Only

Municipalities should remember that industry is the lifeblood of the cities' economy and the source of steadily increasing living standards.

It is the responsibility of municipalities to acquaint industry with the waste treatment problems so that industry may be alerted to their need for waste reduction.

Municipalities should keep abreast of the need for expansion of treatment works facilities as industrial expansion takes place.

Municipalities should remember that the treatment of industrial wastes inevitably leads to shock loads brought about by spills, both accidental and controlled. They should be prepared

with process and equipment flexibility so that shock loads will have a minimum upsetting effect on the treatment works operation.

Municipalities should be as cooperative as possible with industry and have reasonable regulatory measures so that their problems will be small and their streams clean.

Attitudes

Perhaps an analysis of the attitudes of the various elements involved that bear on the industrial waste problem may be helpful in resolving a solution.

Industrial

In industry at least two elements are involved in this problem—management and production. In some industries a waste control group can be added to these.

Management is apt to look at the waste problem from a public relations and cost standpoint. It wishes to satisfy the requirements of regulatory agencies at a minimum cost consistent with production requirements. It desires to be appreciated by the community and does not wish to create any problems with which the public may have grounds for complaint. It also requires that its operations be such as to fill production needs.

On the other hand, production personnel generally wish to fulfill production requirements without regard to wastes, unless production costs can be reduced by waste recovery. It tends to waste materials from its processes in an if-as-and-when manner. In many processes waste recovery is not economically possible, and the simplest procedure is to discharge wastes in the manner and at the rate they are produced. Such a procedure can produce shock loads on treatment works processes and may result in substantial reductions in treatment works efficiency. Controlled discharge or equalization tanks at the industry frequently can prevent such a treatment process upset. Only constant pressure from management and waste control groups can keep wastes within proper bounds.

Municipal

Management of most municipalities has a cooperative attitude toward industry. It is the desire to make its community attractive to industry and therefore it is anxious to assist a cooperative industry. Thus, if industry considers the best solution to its waste treatment to be discharged to municipal sewers and treatment facilities, municipal management will be most receptive to industry's wishes.

On the other hand, treatment works operators are usually reluctant to receive industrial wastes. Such wastes have many effects on the normal biological treatment processes. Waste characteristics are apt to change with rapidity. The rate of discharge may vary from hour to hour in batch operation as the over-all quantities are governed by production schedules.

Furthermore, the quality of the treatment works effluent is apt to deteriorate, especially under conditions of wide variations in loading. In many instances the BOD of industrial wastes is substantially higher than the BOD of domestic sewages. It is possible that an industrial waste can be responsible for a rise in the raw sewage BOD to a municipal plant from 200 to 600 ppm. In this event if the removal efficiency of the plant remains at 90 per cent in both instances, the BOD of the effluent will increase from 20 to 60 ppm. The first effluent can be clear and sparkling, while the second may be turbid and frequently colored. Operators want to produce a continuous low BOD sparkling effluent. However, this is rarely possible when treating substantial quantities of industrial wastes.

In addition there is a potential risk due to accidental or faulty operation of receiving large quantities of such normally excluded wastes as tanks of acid or toxic substances. These may

destroy completely a biological treatment process and would, of course, cause considerable operating trouble in the treatment works.

Thus there exists a situation in which management of both industry and the municipality have a real desire for cooperative solution of the problem, whereas the operating forces of both organizations have opposing views. The treatment works operator does not want the waste with uncontrolled discharge of objectionable material because it complicates his life, and the production department does not want waste control to interfere with production quotas since it already has process and equipment troubles enough without adding this difficult problem to them.

For each of these viewpoints a sound case can be made. The operator at the treatment works has many problems of the mechanical, hydraulic, and electrical variety. The additional process problems brought about by industrial wastes seems just too great a burden. In some cases the treatment works is not designed for the industrial waste load. In others, where the added load has been provided for in the design of the treatment facilities, uncertainties persist regarding the effect of the industrial waste materials on the treatment process. The production staff must answer to management for production costs and quotas. The difficulty of keeping the man that throws the switch or opens the valve aware of the waste problem and the further chore of getting him to be cooperative is a never ending task. In many cases the same utilities are used both in production and waste recovery. Limits of availability of the utility may necessitate reduced production in order to carry on waste recovery. Since the profit from waste recovery is small compared to that from production, the decision is often made to continue production and shut down waste recovery.

With such divergent views regarding the problem, only close liaison and cooperation can effect a happy solution. The industry should maintain close contact with key treatment works personnel. Unusual spills or dumps should be communicated promptly to the plant operator so that he may be able to take the necessary steps to avoid the impending troubles. A major acid spill can be neutralized if caught in time. Additional dissolved organic materials which may overload an activated sludge plant can be compensated for by increasing the air supply. Large quantities of oil or grease can be removed by manual skimming. Only by this type of cooperation can a happy relationship exist. The production group that operates with the "we'll-get-by" or "let-'em-prove-it" slogan is rapidly becoming extinct.

Industrial Wastes in the Activated Sludge Plant

An activated sludge treatment works receiving domestic wastes only is one in which few process problems are encountered. The sewage has a relatively uniform concentration from day to day and there are no potential wastes that may cause great variations in load. This does not imply that problems do not exist in such a plant but merely that the uncertainty of shock loadings and unanticipated materials for treatment is seldom a consideration.

In a plant receiving amenable industrial wastes the loading is apt to change hourly and daily. Typical of the nature of such a loading is the variation from day to day at Peoria where paper, brewery, and packing house wastes predominate among the industrial wastes received. The paper mills operate continuously for 5 to 6 days per week; the brewing and associated activities operate 4 to 6 days per week with both batch and continuous process wastes; while the packing plants produce waste materials in a batch and continuous manner for about 12 hr per day for 5 days per week.

The hourly variation in BOD con-

centration of the raw sewage can change from 150 ppm at 4 AM on Monday morning to 450 ppm at 4 PM the same day. While this is a substantial variation, it is possible to adjust the process variables sufficiently to produce a continuously satisfactory effluent. Note that while the concentration of BOD is increasing threefold the flow is also doubling, thus increasing the population equivalent loading by a multiple of six in the 12-hr period. In the same interval in a completely domestic waste plant the population equivalent might increase to less than twice the 4 AM values.

The day-by-day variation in Peoria is such that on Sunday practically all the waste is of domestic origin with an average population equivalent of about 120,000, while on Thursday the population equivalent could increase to over 400,000 due to the activities of the industries. This daily average variation in load can also be compensated for by process adjustments.

In the conventional activated sludge plant it is difficult to handle such a variation in load, especially in the smaller communities. The Chicago plants are a notable exception to this statement, probably because the shock loads of any one industry are lessened by the very large dilution effect of domestic and other industrial wastes. In many plants the large variations in loadings are accompanied by a loss of purifying activity in the activated sludge and by sharp variations in the sludge settling characteristics. These can be controlled by modified processes (3)(4).

BOD Loadings

It appears that the most important variable in the activated sludge is the oxygen utilization rate. As the BOD loading per unit of sludge volume increases, the rate of oxygen utilization increases. If the dissolved oxygen supply is sufficiently flexible to meet the varying oxygen utilization rate, the process will operate successfully; if not, the process will deteriorate. The process modification and the type of aeration used will in a large degree control the quantity of BOD loading in a given system of aeration tanks. Loadings of 35 lb of applied BOD per 1,000 cu ft of aeration tank capacity are commonly used for design purposes. Loadings in the order of 50 lb of applied BOD per 1,000 cu ft are possible by modifying the process using conventional aeration diffusers. Loadings of 80 lb of applied BOD per 1,000 cu ft are possible using both process and aeration device modifications (5). Loadings in the order of 400 lb of applied BOD per 1,000 cu ft are possible through the use of special aeration devices when high BOD concentration (1,000 to 2,000 ppm) industrial wastes are to be treated. Thus it appears from a BOD loading point of view that conventional aeration tanks have a much greater capacity for treatment of amenable industrial wastes than was thought possible in original design.

Sludge Control

Many amenable industrial wastes contain large quantities of dissolved organic materials. These materials are frequently carbohydrates which stimulate the growth of sludge bacteria and their exudates (synthesis) thereby creating materials of low density and with poor settling characteristics. Since the success of the activated sludge process depends on the separation of the sludge from the purified wastes, the settleability of the sludge is of prime importance to the effective use of the process.

It therefore follows that the sludge with the best settling characteristics requires a minimum of settling tank capacity. At the present time two means are available to control the density of the sludge: (a) recycling digested sludge to the process (6), and (b) chlorination (7). The former is of continuous benefit and the latter is of a

temporary nature. In addition to the factor of sludge settleability the functioning of final settling tanks is dependent on design of influent devices and effluent weirs. Proper design of these facilities and accompanying sludge of good settleability can be responsible for an increase in the capacity of settling tanks to influent rates of over 3,000 gpd/sq ft with a slight increase in suspended solids. At Peoria modifications of influent devices and effluent weirs resulted in an increase of 5 ppm in suspended solids with inflow rates of 3,110 gpd/sq ft as comapred with former inflow rates of about 1,000 gpd/sq ft. The average sludge volume index of the activated sludge was 49 and average suspended solids in the aeration tanks was 3,500 ppm. The period of this study extended over two months and included 23 comparisons.

Thus it follows that the existing conventionally designed activated sludge plants have sufficient aeration tank and final settling tank capacity to accommodate substantial quantities of industrial wastes by modifying the process, the aeration introduction in the aeration tanks, and the influent and effluent distribution and collection in the final settling tanks. The manner in which these alterations are made is a function of the type and quantity of industrial waste (particularly the BOD concentration of the resulting combined waste) and the original tank design.

One of the important factors in the design of an activated sludge plant for treating combined wastes is the return sludge facility. As the BOD concentration of the combined waste increases, the return activated sludge-waste ratio should increase. It is customary to design conventional activated sludge plants with a return activated sludge-sewage ratio of 1:4. Under conditions of the high loadings of aeration tanks and final settling tanks noted in this discussion a 1:2 ratio is required. When uncertain waste conditions exist, a 1:1 ratio can be used to advantage.

Final Settling Tanks

Great differences exist in the designs of existing final settling tanks. Modifications of influent and effluent conditions require study and experimentation. Means of increasing sludge withdrawal may be the only factor limiting the efficiency of mixed liquor settling. On the other hand, the influent distribution and effluent weirs may require redesign. Since the cost of modifying these facilities is but a very small fraction of the cost of additional tank volume, it is easy to justify the cost of such experimental changes.

Pilot Studies Recommended

When the effect of an industrial waste on the sewage treatment works is not known, and when existing facilities require modification, pilot plant studies should be made. This takes considerable technical effort, and should be undertaken as a joint activity of both industry and the municipality. The pilot plant can point up specific problems that are not ordinarily apparent. Many factors, such as sludge settleability, cannot be determined in the laboratory. The design of aeration devices, where very high BOD concentrations are to be treated, can be estimated by designers but only an installation in a pilot plant or in an existing prototype tank can really evaluate its effectiveness.

Summary

Specific experience with the treatment of combined industrial and domestic wastes in a municipal activated sludge treatment plant has led to the following general conclusions regarding such combined treatment:

1. Combined treatment can be an effective solution.
2. The total cost is generally lower than would be encountered if separate treatment is practiced at the industry.
3. Industry finds this practice desirable from the standpoint of efficiency

of treatment, public relations, personnel, and capital outlay.

4. Modification of existing activated sludge treatment works can greatly increase their capacity to treat wastes.

5. The costs of combined treatment should be shared by industry and the municipality on a fair basis.

6. The primary essential of successful combined treatment is close liaison and cooperation between industry and the municipality.

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DISCUSSION

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It should first be noted that the comments on this paper may be influenced by the method of administration of pollution control in Connecticut. The operation of sewage treatment plants after construction is charged to the Bureau of Sanitary Engineering of the State Health Department. The abatement of industrial waste is the responsibility of the Water Resources Commission. Under this arrangement, the remarks have less weight because the Water Resources Commission is not involved in the details of the operating difficulties caused by the discharge of industrial wastes to sewage treatment plants. On the other hand, this discussion may have more weight because there would be a natural tendency to solve the industrial waste problems at the expense of the companion department—yet the difficulties with handling industrial wastes at sewage treatment plants have become so well appreciated that this easy method of solving the problems is not ordinarily used.

Problems Encountered in Connecticut

The policy of the Water Resources Commission to discourage the discharge of industrial wastes to sanitary sewers is based on experiences which range from troubles with excessive clean water to the upsetting of an activated sludge treatment by chromium. The metallurgical industry is well established in Connecticut, and a number of municipal sewage plants have experienced difficulties with toxic wastes from plating operations, in digestion facilities as well as in the secondary processes.

In fact there are two sewage treatment plants in the State in which it was recognized even in the design stage that the toxic industrial wastes were so extensive that digestion could not be carried out. In at least six cases the industrial wastes in the sewer sys-

tem was a fact at the time of construction of the treatment plant and their acceptance was an important consideration in design.

Such problems are well known and can be anticipated. However, the range of substances which constitutes industrial waste can cause no end of difficulties not previously anticipated. One plant has had fairly continuous difficulty with operation due to industrial discharges of sawdust. At another large treatment plant, pigs' toes discharged from a meat processing plant caused great difficulties with mechanical equipment in and preceding the treatment plant. Metal chips have broken screen mechanisms. Some wastes, although not affecting treatment, have created an excessive chlorine demand in order to provide required residuals. Rubber bands as well as fibers have made screens inoperative. Strong acids have caused difficulties in sewer systems as well as in treatment plants. Any industrial waste source at any time is apt to discharge oils, which can be particularly difficult in the operation of a treatment plant. Once industrial wastes are accepted in a sewer system it is difficult to prevent discharge of many materials which were not originally contemplated.

These difficulties also have occurred when wastes were accepted on the basis of a pretreatment. Policing and control of these pretreatments is itself a problem to the enforcement agency and may be as difficult as supervision of the operation of an industrial waste treatment plant.

The Regulatory Approach

The paper by Kraus deals with amenable industrial wastes. As a general policy it is believed that the Water Resources Commission would agree that amenable wastes, if such wastes can be treated more economically at a sanitary sewage plant, should be so handled. However, the problem is to define amenable. It appears that all that has been done is to classify a problem without providing a solution. The definition of the term amenable is as difficult as the problem of determining which industrial wastes will not affect a sanitary sewage treatment plant. A word such as amenable, when left to a layman's definition, can be troublesome. If the Commission adopted a policy based on such a word, it seems certain that hundreds of job platers in Connecticut would be trying to convince the staff that their brands of chromium or cyanide were the most amenable which could be purchased in the open market.

Kraus reported from the questionnaires that 17 per cent of plants reported that there were problems that could not be solved, and that 61 per cent experienced lesser problems arising from acceptance of industrial wastes. It appears to be a conclusion from these statistics that there has been proven a case for the acceptance of certain industrial wastes as a matter of policy. Statistics vary with viewpoint and it is felt that these warrant the opposite conclusion. A yardstick is needed to appraise these two conclusions and since one of the considerations is the possible financial advantage to industry, it may be proper to use industry as the criterion. One analogy may be that if an industry constructed one hundred one-half million dollar processes and 17 per cent of them proved to have uncontrollable difficulties and that another large percentage of these hundred processes had to be revamped to take care of conditions caused by a policy determination, then management would not consider the investment sufficiently sound to warrant repetition without a revision of policy. If it is assumed that the enforcement agency has the same attitude toward a repetition of a public investment then it would follow that policies should not be developed that will be likely to cause the same percentages of failures in the future.

The author concluded on the basis of influent and effluent samples that operating problems did not appear to reduce sewage treatment efficiency. However, without knowing otherwise it seems fair to assume that the samples were not consistently taken while the operator was experiencing the more difficult problems.

It is also a conclusion that industry should make available all information relative to the nature and quantity of its wastes. To be practical the fact must be faced that with rare exceptions industry does not know the nature and quantity of its wastes. It is ridiculous to assume that the small job plater can appreciate the "gray" range of cyanide concentrations that may or may not be toxic to friendly bacteria in a sewage plant.

It has been axiomatic in the Water Resources Commission for thirty years that the greatest amount of industrial pollution abatement can be accomplished by close cooperation with industries. A personal conclusion in working with industry is that it can adequately protect its own interests. It appears that enforcement agencies should maintain a position equally as strong for the protection of the public's investment in sanitary sewage facilities. Negotiations on such a basis provide the fairness which is noted to be a need. Cordial cooperation is also indicated as being a necessity. In negotiations for industrial wastes treatment, no industries have been found that were not cordial, but it is a fact that in the State of Connecticut there are many cordial but uncooperative industries as well as many cordial and cooperative industries.

In establishing policies to control the industrial waste problem it is felt that the sewage plant operator must be protected from undue headaches from industry. An example of such a procedure as recommended by the author is the prompt reporting of a harmful dump. A sewage plant operator would not be particularly happy with such a report at 2 AM. Neither could it be expected to make him think more highly of the enforcement agency which promoted the procedure.

The paper notes that industry should be as cooperative as possible with regulatory and local treatment works agencies so that its problems may be few and its profits large. The millennium will have arrived when industry will be even more cooperative so that the agencies problems would not be multiplied and the public costs will be smaller.

In using the data from the questionnaires, it is felt that administrative agencies should be careful not to adopt policies which are so broad as to allow in future years the development of a great number of difficult operational problems which must be solved with public funds allocated to abatement enforcement agencies.

Although there will always be appreciation of the problems and the financial difficulties of industry in providing satisfactory amelioration of industrial wastes, it is a firm conviction that regulatory policies should have the factor of safety on the side of protection of the public investment.

Stream Pollution

BIOCHEMICAL DEGRADATION PRODUCTS—A NEW DIMENSION IN STREAM POLLUTION *

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Water quality standards are generally intended to be clear cut and definitive. Unfortunately it has not been possible always to describe all facets of stream pollution in unique or precise terms. Stream pollution standards as they have developed are interesting mixtures of rigorous limits of an exact nature on the one hand and broad generalized requirements on the other. It has become common practice to prescribe limits for pH, DO, phenol, cyanide, and chromium, among others, with the same sense of confidence and reality as those for COD, BOD, tastes and odors, etc. There appears to be no middle ground.

During recent years there has been an increased interest in the fate of synthetic organic chemicals in receiving waters. Reports of zero BOD organics, of persistent substances such as synthetic detergents, and of numerous organic substances being found in domestic water supplies (1) raise some interesting questions concerning stream pollution criteria.

The purpose of this study is to examine some of the currently accepted practices of measuring stream pollution in the light of recent changes in the nature of the materials reaching surface waters. Reports from the literature, together with research conducted by the author, form the basis for this study.

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Limitations of BOD and COD Measurements

The use of biochemical and chemical oxidative procedures as a measure of organic pollution has become common practice. The generally accepted practical interpretation of such information is—the greater the oxygen demand the greater the degree of pollutional strength, other things being equal. Experience tends to substantiate this line of reasoning. Theoretical interpretations of these data have not enjoyed such unanimity of opinion or of experience.

One of the most serious theoretical misinterpretations stems from attempts to explain events taking place in a BOD bottle by monomolecular reaction kinetics. While the simple expression

$$\frac{dL}{dt} = -KL$$

has found widespread practical use it does not follow that the biochemical conversion of organics behaves in this manner. The analogy between ultimate BOD "L" and organic food material has led many to an erroneous concept. It has become common to consider the residual BOD at any time as due to an unused portion of the original food material present at the start. In other words the BOD reaction proceeds by assimilation of whole molecules of the original organic material present. Thus one molecule of food is converted to carbon dioxide,

water, or cell tissue before the next is used. In the case of readily assimilated substances such as simple sugars something approaching this appears to take place. With more complex organics evidence points to something different.

Attempts to correlate BOD and COD values are good examples of the inadequacy of the concept of whole molecular conversion. If the BOD reaction was as described by the monomolecular reaction equation, then it should be possible to calculate BOD values from COD data or vice versa. With few exceptions this has not been possible. Obviously there is more involved than a straightforward molecule by molecule destruction. Actually there is considerable evidence, both in nature and from practice, indicating that the so-called BOD reaction is a complex stepwise procedure. While it is entirely possible that many simple substances can be assimilated completely by one species of microorganism, it is equally probable that many organics are destroyed in a series of symbiotic steps or processes. Termination or interruption of a symbiotic type of relationship would result in the formation or accumulation of partially degraded by-products. Many such events have been recognized in nature. In fact, whole industries have been built on the use of biochemical production of organics. The possibility of such events occurring in biological treatment units and in receiving waters should not be overlooked.

BOD and COD data are of considerable value in determining the oxygen requirements for disposing of a waste. Such data by their very nature tell little of the events leading up to the point at which oxygen utilization values are measured. Information obtained from these tests does not describe the qualitative nature of the residual materials which may be present.

Experimental Results

During a study of the oxidation of organics by acclimated activated sludges evidence was obtained which indicated that biochemical degradation products might be formed from certain classes of compounds. The results of research aimed at determining the nature of the suspected biochemical end products are reported herein.

Materials Studied

The data were obtained during an investigation of the biochemical behavior of synthetic detergents. A number of related organics were studied in addition to the major types of synthetic detergents. Included in the materials studied were alkanes, high molecular weight fatty acids and alcohols, low molecular weight ethylene glycols, and a number of alkyl benzenes. The list of substances studied has been discussed in detail elsewhere (2)(3)(4).

Experimental Procedure

The method of study was to develop acclimated activated sludges for each substance and to measure its biochemical oxidation by the Warburg apparatus and by the standard BOD technique. The exact experimental procedure has been described earlier in detail (2)(3). In addition to these biochemical oxidation determinations, cell-free extracts were taken from activated sludge systems and analyzed for their organic residues by infrared spectroscopy.

Biochemical Reactions

It is generally recognized that the assimilation of an organic compound by living cell tissue involves a number of enzymatic changes or steps. The exact number and types of enzyme-induced steps depends upon the nature or chemical structure of the food substance involved (5)(6). A number of commonly occurring enzyme reactions have been recognized (6). Most notable of these from the standpoint of waste treatment are: (a) hydrolysis, (b) β oxidation or degradation of aliphatics, (c) ω, or terminal oxidation of satu-

rated endings on carbon chains, and (d) fission or rupture of ring structures and unsaturated aliphatic chains.

The biochemical oxidation reactions traced by the Warburg apparatus (2) (3) have been reexamined in terms of the probable major enzyme reactions involved. The observed reaction rates during the first 30 to 60 minutes were taken as a basis for analysis and comparison. During the early stages of most of the biochemical reactions the original substrate molecules should be involved. At subsequent times the situation is more obscure.

The relative rates at which certain reactions appeared to take place in the activated sludge systems studied have been recorded in Table I. These relative reaction rates are based on the oxygen utilized by 3,000 mg/l of acclimated sludge in the presence of 100 mg/l of a specific organic compound when employed as the sole source of organic carbon. The apparent rate of conversion of stearic acid by β oxidation was taken as the basis for comparison. Since the results are limited to a summary of observations during this investigation these values may be somewhat problematical.

As already observed many enzyme reactions may be involved in the sequence of events leading to the degradation of an organic compound. The kinetics of complex multireaction systems have often been characterized by one rate-controlling reaction. Inspection of the data presented in Table I indicates that certain reactions may

TABLE I.—Probable Relative Enzyme Reaction Rates in Acclimated Activated Sludge

Reaction	Reaction Site	Relative Rate*
(a) Hydrolysis		
$R—SO_4Na \xrightarrow{+H_2O} R—OH + NaHSO_4$	Alkylsulfate	100
$RCON(R')(R'') \xrightarrow{+H_2O} RCOOH + HNR'R''$	Sulfonated amide	100
$RCOOR' \xrightarrow{+H_2O} RCOOH + R'—OH$	Sulfonated ester	100
(b) Fission		
Unsaturated aliphatic	Oleate	88–96
Benzene ring	Benzene	22
(c) Terminal and ω Oxidation		
$RC—OH \xrightarrow{1/2\ O_2} RCOOH$	Aliphatic alcohol	67–100
$—H_2C—CH_3 \xrightarrow{3/2\ O_2} —H_2C—COOH$	Aliphatic terminal	37
	Aromatic alkyl terminal	33–38
	Aromatic alkyl side groups	10–33
(d) β Oxidation		
Aliphatic carbon chain	n-alkylbenzene SO_3H	100
	Stearate	100
	n-aliphatic alcohol	100
Ether linkage	Ethoxy polyglycols	67–83

* Oxygen utilization for β oxidation in saturated aliphatic acid chosen as basis of comparison.

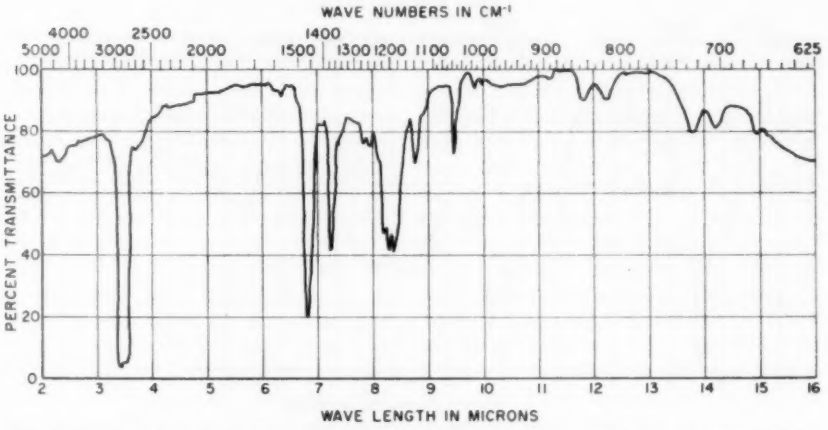

FIGURE 1.—Infrared spectrogram of para-n-dodecyl benzene sulfonate in pure form—nujol mull.

act as impediments. For example, in the case of the alkyl benzene sulfonates, indications are that difficulties may be encountered both in the alkyl group and in fissioning the benzene ring. If such events do take place then some evidence of it would be expected in the form of biological degradation products. In order to check this hypothesis, material was withdrawn from activated sludge systems and analyzed for the presence of postulated by-products.

Infrared spectrograms are shown (Figures 1, 2, 3, and 4) for two of the alkyl benzene sulfonates studied. One of these materials was pure para-n-dodecyl benzene sulfonate obtained from the Atlantic Refining Co. The other substance was a narrow distillation cut of commercial keryl benzene sulfonate. This last substance was furnished by the Procter and Gamble Co. Spectra are shown of the original material and of the material remaining after 24 hr of contact with acclimated activated sludge. Each substance was

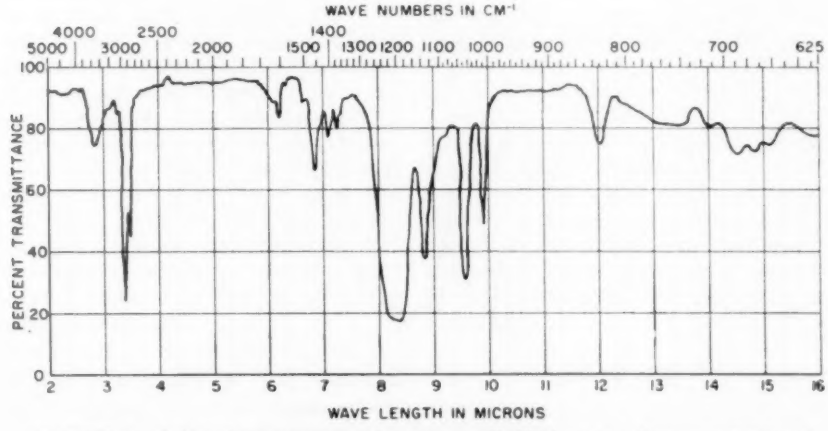

FIGURE 2.—Infrared spectrogram of a narrow distillation cut of commercial keryl benzene sulfonate in original form—carbon tetrachloride solution.

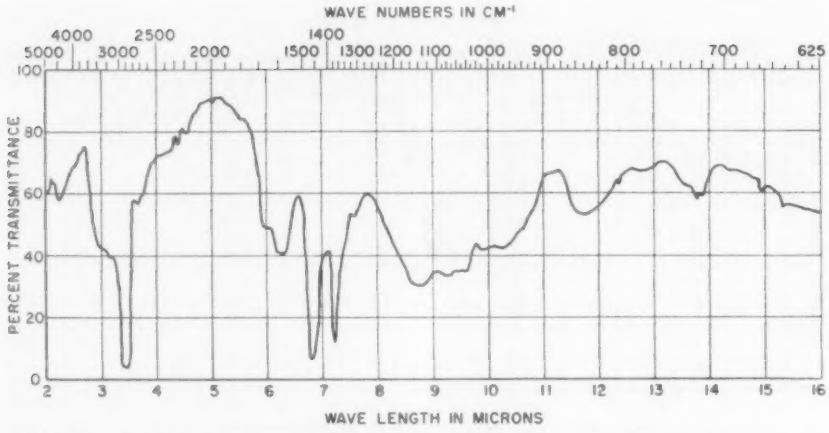

FIGURE 3.—Infrared spectrogram of para-n-dodecyl benzene sulfonate after 24 hr of contact with acclimated activated sludge—nujol mull.

employed as the sole source of organic carbon. Sludge in an endogenous state of respiration was washed with tap water before use to elude any residual organics.

Inspection of these spectrograms discloses the presence of numerous oxidized aromatic derivatives of the original organics. Absorption spectra for aromatic alcohols, ketones, aldehydes, and acids are present (7). Data in Table I indicate that a benzene nucleus might tend to restrict or retard complete degradation of such molecules. The infrared spectra tend to confirm this concept. A somewhat similar situation has been observed in the case of assimilation of alkyl benzenes by animals (8)(9).

Discussion

Experience with persistent organic substances has led some to the conclusion that stream pollutants cannot be evaluated satisfactorily in terms of BOD alone (10). Because biochemical

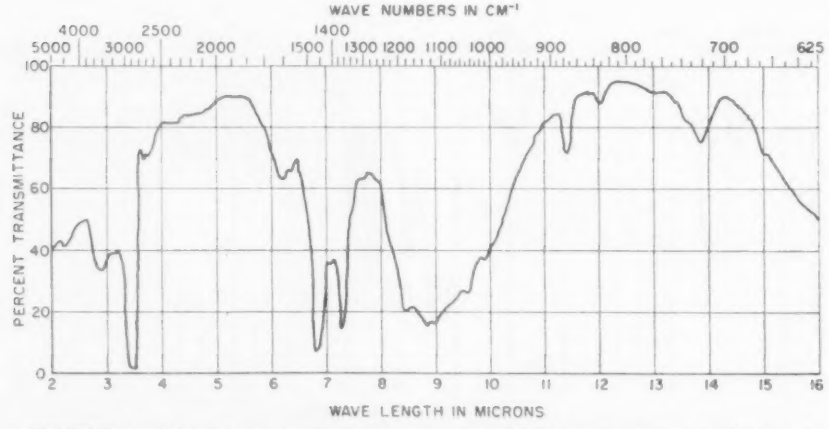

FIGURE 4.—Infrared spectrogram of a narrow distillation cut of commercial keryl benzene sulfonate after 24 hr of contact with acclimated activated sludge—nujol mull.

oxidation can create real and serious problems, tests aimed at assessing oxygen requirements have a practical meaning and value. Few will argue with the importance of BOD data as a measure of a significant form of stream pollution. However, the question should be whether this is the only aspect of biochemical pollution with which there should be concern.

The work of Ettinger (10), Ludzack and Kinkead (11), and Sawyer *et al.* (4) calls attention to the fact that many types of organics may persist in receiving waters for extended periods of time. Obviously any material that persists in a stream is as important, until proven otherwise, as one which undergoes rapid biochemical degradation. This concept has led to the rather broad generalization that there are two general classes of materials: (a) those which are easily oxidized and (b) those which are not. Pursuing this line of reasoning a little further has lead some to the conclusion that compounds exhibiting ease of biochemical oxidation are of no consequence except in terms of DO depletion. Both Cairns (12) and Ettinger (10) have raised some interesting questions in regard to this latter concept. Namely, are organic end products produced which may be of equal or greater significance than the original waste materials?

Cairns (12) points out that little attention has been given to the effects of the compounds formed by attenuation of wastes after they enter the stream. He makes the additional statement that at times these secondary compounds are more toxic than the originals. Ettinger (10) has recognized that both new cell tissue as well as soluble metabolic end products may cause a residual BOD long after the original chemical is gone.

It should be recognized that an apparent termination of the so-called BOD reaction is not evidence in all cases that the original food material has been converted to cell tissue, carbon dioxide, and water. The BOD test is a relative thing. The rate and extent to which organics are oxidized are dependent upon the microorganisms present and the chemical structure of the food material. Even under carefully controlled laboratory conditions the course of the BOD reaction may be difficult to interpret (13). McKinney and Jeris (14) point out that as long as a compound fits into the common metabolic pattern the metabolism is rapid. Once the chemical structure causes a deviation from the common pattern it is broken down very slowly and with much difficulty on the part of the microorganisms.

The findings of this research indicate that BOD values observed for many substances may be related to degradation of a portion of the molecule only. In the case of the alkyl benzene sulfonates described herein much of the oxidation observed appears to have been centered in the alkyl groups. A somewhat analagous situation has been described by Ludzack and Kinkead (11) during a study of the biochemical oxidation of oils. This study indicates the ability to identify the presence of oxidized alkane derivatives by the use of infrared spectroscopy. It does not always follow that biochemical oxidation would continue to be centered in the original molecule. Through such operations as hydrolysis and fission the original organic may be converted into two or more fragments. Some of these derivatives may be easily oxidized. Others may persist for considerable periods of time. Conditions below many waste outfalls might be described in terms of a unique fractionating mechanism with biochemical oxidation products extending downstream in relation to their persistence and sequence of formation.

Conclusions

On the basis of the foregoing review and of the experimental results the following conclusions are drawn:

1. Organic stream pollutants generally cannot be evaluated adequately in terms of BOD or COD alone. Neither test allows description of residual organics which may be present after varying periods of biochemical oxidation.

2. Biochemical degradation intermediates or by-products have been demonstrated during the breakdown of oils and alkyl benzene sulfonates. The possibility of their production from a number of other sources exists.

3. Oxidation of an organic compound may be related to a portion only of the original molecule. Through hydrolysis and fission a substance may be broken into two or more fragments. It is entirely possible that certain fragments may be relatively resistant to oxidation, whereas others may be rapidly oxidized.

4. Many consecutive enzyme reactions may be involved in the degradation of an organic. Some of these reactions have been found to take place at widely differing rates. Evidence indicates that certain enzyme reactions such as fissioning of the benzene ring may regulate the rate at which a substance can be oxidized. There may be cause for biochemical degradation products to accumulate at such reaction points.

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BASIC DATA FOR WATER SUPPLY AND WATER POLLUTION CONTROL *

By Richard S. Green

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Basic data are fundamental building blocks needed for all water use planning, on which the Nation's economy depends. It is desirable to emphasize the great and growing need for factual information in the support of water supply and water pollution control activities, to point out some of the most important deficiencies in present activities, and to suggest ways in which these deficiencies may be met.

The fullest possible information on existing facilities and future needs for all water supply and sewage and industrial waste treatment in the entire country is fundamental to productive efforts by water pollution control authorities and others concerned. There is need for facts upon which to base comprehensive pollution control plans; for facts on the exact nature of water supply situations and sewage treatment needs; for facts on which to base effective enforcement procedures; and for facts which will further the understanding and cooperation of industry in solving pollution problems. These facts are called "basic data."

Effective administration of water pollution control activities calls for continuous acquisition of these data and their analysis as a guide to what has been done, is being done, and still needs to be done.

Types of Basic Data

To clarify the discussion, the necessary information may be considered to fall in one of the following three broad areas:

1. Inventory data.
2. Economics data.
3. Water quality data.

Inventory data cover physical, operating, and related information, including deficiencies or needs, on all water supply and sewage and industrial waste treatment facilities in the country. Economics data deal with levels of construction activity in the water works and sewage treatment field, including unit costs, service charges, financing of facilities, and similar items, as well as measures of damage done by pollution and the benefits of pollution control. Finally, water quality data reveal the quality of the waters of the United States from the point of view of pollution, thus providing the ultimate basis for planning and for continuing review of progress in controlling pollution of the Nation's streams.

Normal Sources of Basic Data

Each individual who has any responsibility in the use of water or the protection of its quality, whether in an industrial plant, a municipal office, a state agency, or the Federal Government, has an interest in at least some of this information in his work. In one way or another while carrying out normal duties, individuals actually develop many of the facts needed to fill out the over-all requirements. Records are kept of the volume and strength of effluent from treatment works and of

* Presented at the 1957 Annual Meeting, Texas Water and Sewage Works Association Short School, College Station, Texas; March 3–8, 1957.

the cost of plant operation or expansion. Records of diminished river flows or falling ground water tables, as well as the changes in water consumption by municipalities, industries, and agriculture, are noted with concern. The dissolved oxygen, the chlorides, the nitrates, the silt load, and a host of other measures of water quality in our streams are watched. Financial information for the municipal bond market is the concern of some. The really significant point is that while each worker produces some of this information, all need much more than is contributed by any individual. This is the key to the problem of basic data on water. There is a wealth of information available but much of it never gets maximum use because it is in isolated file drawers or notebooks and not in readily available public documents. Essentially, any proposal to alleviate this situation must involve suggestions for smoking out these buried facts. This information must then be assessed to see how nearly it comes to satisfying all the data requirements so that productive steps can be launched to fill the gaps.

Needs and Deficiencies

The various needs for these data are different, particularly from the point of view of national requirements as distinct from the requirements of local or state agencies. An example in one field emphasizes this difference. The Federal Government must have detailed information about individual water supply facilities and future requirements for the purpose of studying national trends and needs in water treatment or water handling practice, and to be able to supply on short notice reasonably accurate preliminary information on installations of specific communities. Many federal departments and large segments of industry need the detailed tabulation of facilities as well as the resulting analyses. The Corps of Engineers, the Forest Service, the Bureau of Reclamation, and various units of the Department of Commerce are examples of organizations using these studies routinely. Beyond this, the data are necessary for the vital job of establishing materials requirements, water supply expansion potentials, basic facts for use in mobilization planning, and in civil defense planning.

Except in a relatively few areas, all the information needed for adequate national planning in the water field is produced by some other group or agency than the Federal Government. As a further explanation of the example of the water supply facilities, all the state health departments have these data tabulated. It is true that limitations of state personnel sometimes make it impossible to keep such data current, but at least the states do have the mechanism for accumulation. Since an important objective is to bring out deficiencies in existing data on water and water pollution, it is pertinent to emphasize this last point. For not only must the data already coming into the files of many local and state agencies be effectively assembled, but also it is necessary to assure that those files are themselves complete. This situation does not now exist. In fact, for some kinds of data very little really solid material could be brought together in any canvass of state agency files. One example of this has been the lack of information in some areas of the country about construction levels in the waste disposal field. Another much more prevalent deficiency is the lack of information about the kinds and strengths of industrial wastes which are now reaching the Nation's streams.

General Strengthening Activities

In making proposals for strengthening basic data activities in the field of water in the United States it is emphasized that this task is great and that it must be undertaken with maximum

efficiency and the greatest possible use of available records and resources. Specifically, the state agencies responsible for water supply and water pollution control activities should be encouraged, and if necessary assisted to strengthen operations in this field. This proposal would prevent wasteful and unsatisfactory duplication of effort by the Federal Government. In developing its plans for improving basic data operations in the water supply and water pollution control field, the Public Health Service will be bound by these principles.

The Public Health Service has been gathering facts in the field of water supply and water pollution control for many years. As early as 1915 the Service, with the cooperation of many of the state health departments, compiled an inventory of water supply and sewage facilities. In later years the inventory activities were continued and expanded and extensive collection of stream sanitation data was added. As of last year, certain of the national basic data activities in water handled in the Public Health Service were fairly well established, understood, and used. The work had even expanded into such specialized and vital fields as the assembly and analysis of data covering the vulnerability of the Nation's several hundred larger water supply systems to a nuclear bombing attack.

The President's Advisory Committee on Water Resources Policy recommended strengthening such work and with the passage of Public Law 660, the present Federal Water Pollution Control Act, the Service is now specifically authorized by law to undertake these activities. Concurrent with the development of long-range plans for meeting these directives, the Service has taken steps to improve its operations by adding a few vitally needed specialists to its staff, particularly in the neglected area of analysis. All data handled on a continuing basis are now being processed by modern machine tabulation and analysis techniques. These methods have greatly speeded up operations. Even more important, it is now possible to perform complex and detailed analyses of data on a state-by-state basis. The results of these studies will, of course, be made available to the state agencies concerned.

Specific Strengthening Activities

Some of the recent changes which have been made to perfect current USPHS operations are pertinent at this time. Tentative plans now being discussed for filling the known gaps are especially important.

Inventory Data

At the present time tabulated data on public water supply facilities for the larger communities are gathered and periodically released. Most of those involved in water supply work are familiar with this activity. Schedules have now been established for assembling data for all the remaining water facilities for the smaller communities in the United States so that a national water facilities inventory can be published within about a year. The last such national inventory is about ten years old.

One of the deficiencies in the field of basic data on physical facilities is a lack of full information about municipal and industrial wastes and waste treatment facilities. Approximately 40 of the states had supplied the Public Health Service with data covering these facilities by the beginning of 1957. In some cases, however, these data were as much as four years old. After careful consideration of all the factors involved, it was decided to attempt a national inventory of waste treatment facilities, including data as of December 31, 1956. Considerable progress has now been made. National compilation and analysis will be made soon after the data are received. How-

ever, general cooperation is needed to reach this goal. The USPHS Regional Offices are a part of this cooperative effort.

Economics Data

During the past year the Public Health Service has made considerable progress in its coverage of such data as those dealing with contract awards for water supply and sewage facilities construction and calculation of levels of construction put-in-place, both of which are essential parameters of progress, or lack of it, in these fields. The first really broad assembly of data on cost of construction in the municipal sewage treatment field that has been undertaken for many years has begun. Still another very important activity within the Public Health Service considers the fundamental concept of the value of water and the development of cost-benefit relationships which can be applied to particular spheres of interest in the ever-increasing competition for water resources.

Water Quality Data

Probably the biggest job ahead, and certainly one which is receiving most careful attention, covers the entire area of water quality. It is already known from preliminary evaluation of this problem that there are large deficiencies to be met. It is true that a vast amount of information about the quality of the Nation's streams does exist, but by and large much of that which has been gathered has been for the purpose of meeting the particular requirements of a specific study of a given stream, and therefore does not necessarily add very much to the basic need for continuing data through which to evaluate long-term progress in water pollution control. The Service feels that its greatest contribution toward the development of sound water quality data ultimately will come through the strengthening and reenforcement of state and local facilities. Specifically, it is hoped to expand the laboratory reference service of the Robert A. Taft Sanitary Engineering Center at Cincinnati to the point where many more state and local laboratories can take advantage of its facilities to judge the quality of their own laboratory work, to correct any deficiencies uncovered, and in turn to help develop improved techniques which will be of general use. Another objective is to strengthen the USPHS laboratory training facilities in order to make available to other laboratory and associated workers the skills which will become more and more important in a field that is rapidly becoming more complex.

It is felt that for long-term development in the field of water quality data in the United States, as a whole, there will always be a need for a baseline of analytical work to be done by the Federal Government. Therefore, the Public Health Service is now setting up a network of 50 water quality sampling stations in 14 major river basins in the United States in cooperation with state and local agencies. These stations are being selected to furnish data for a broad national framework which will be complemented by intrastate networks presently being developed in many states. It is expected that the Public Health Service basic network will be expanded to a level of 250 to 300 stations as conditions permit.

The principal objectives of this activity are: (a) to provide continuous information on the nature and extent of pollution affecting water quality; (b) to obtain information on changes in quality as affected by changes in water use and development; (c) to acquire data that will guide water pollution control programs and the development of comprehensive water resources programs; and (d) to provide valuable data for selection of industrial and domestic water supply sites.

In addition to analytical data developed by the collaborating labora-

tories for older and more conventional analyses, the Public Health Service through its Sanitary Engineering Center will perform more recently developed tests for measuring some of the newer contaminants entering the Nation's streams. Included among these will be measures of: (a) organic contaminants, which are increasing rapidly due to large expansion of the chemical industries, and (b) radioactivity to develop background levels prior to expansion of peacetime uses of atomic energy expected to develop during the next several years.

The conventional quality tests, such as biochemical oxygen demand, dissolved oxygen, and routine bacteriological, as well as radioactivity analyses, will be performed weekly, and analyses to measure the biological population and the presence of chemical organic contaminants performed monthly. Data from both the local participating laboratories and the Sanitary Engineering Center will be assembled and processed in the Washington headquarters of the Water Supply and Water Pollution Control Program of the Public Health Service. The data will be published annually.

Summary

It is again emphasized that there is a vital need for cooperative effort to improve these basic data activities in the water and sewage field. It is well known that there are major deficiencies in the data—voids which are of direct concern to everyone responsible for water pollution control as well as for water supplies. The basic information is generally needed to make satisfactory progress in meeting the increasing demands for water and in conserving the existing supplies through pollution control. If these facts are not available many serious and costly errors will be made.

To accomplish this cooperative effort the Public Health Service will continue to give every possible support to this program.

AMERICAN WATER WORKS ASSOCIATION OFFICERS

The American Water Works Association has announced the following schedule of nominations for officers for the coming year:

President: Lewis S. Finch, Vice-President and Chief Engineer, Indianapolis Water Co., Indianapolis, Ind.

Vice-President: Lauren W. Grayson, General Manager and Chief Engineer, Public Service Dept., Glendale, Calif.

Treasurer: William J. Orchard, Director, Wallace and Tiernan Inc., Belleville, N. J.

This slate of officers will be final if no further nominations are filed prior to March 1, 1958.

THE OPERATOR'S CORNER

CONDUCTED BY DONALD P. SCHIESSWOHL

REMOVAL OF SEWER ODORS BY SCRUBBING WITH ALKALINE SOLUTIONS *

BY C. W. BEARDSLEY, N. J. KROTINGER, AND J. H. RIGDON

Respectively, Director, and Materials Testing Engineering Assistant, Bureau of Standards; and Chemical Engineering Associate, Bureau of Engineering, Department of Public Works, Los Angeles, Calif.

The odor control problem in the collection and treatment of sewage has been called one of the major unsolved problems of sanitary engineering. The City of Los Angeles is still faced with the problem of deodorizing large volumes of putrid sewer air satisfactorily, after many years of trying different methods of odor control.

During peak odor-producing months, present-day odor control methods fail to produce satisfactory results. This situation causes recurrent complaints along certain sections of the sewer system.

Unfortunately, no method is immediately available to process 10,000 cfm of highly offensive sewer air so that it would be entirely satisfactory to a residential area population and still not be prohibitively expensive.

Odor Control Efforts

Some of the methods of odor control that have been investigated in the laboratory and in the field by the City of Los Angeles are:

1. Chemical cleaning of sewer lines.
2. Aeration of the sewage.
3. Addition of nitrate.
4. Precipitation of sulfides in sewage with metallic salts.
5. Increasing the pH of the sewage.
6. Addition of chromates to the sewage.
7. Activated charcoal absorption of sewer odors.
8. Soil absorption of sewer odors.
9. Dilution of sewer odors.
10. Combustion of sewer gases using catalytic and non-catalytic methods.
11. Counteraction and masking in the sewage and sewer atmosphere.
12. Chlorination of the sewer atmosphere.
13. Mechanical cleaning of the sewer lines.
14. Chlorination of the sewage.
15. Alkaline scrubbing of the sewer atmosphere.

Some of these odor control methods are satisfactory under limited or special conditions. From the viewpoint of residents near sewer ventilating stations, only a 100 per cent removal of the sewer odors is satisfactory. From the viewpoint of city officials, complete removal would be prohibitively expensive.

For several years, the City of Los Angeles has been using masking agents.

* Presented at the 1957 Annual Meeting, California Sewage and Industrial Wastes Assn.; San Diego, Calif.; May 1–4, 1957.

Repeatedly, at the peak of the odor season, many odor complaints have been received.

Sewer ventilating stations located on the large sewer lines are one of the major sources of odor problems. These ventilating stations are necessary to either reduce hydrogen sulfide corrosion or keep positive pressures from building up in the sewers. If positive pressures are allowed to build up in the sewer, odors will escape from house vents and other openings, causing many complaints. These obnoxious odors are therefore concentrated at the ventilating stations.

Previous investigations by the Bureau of Standards have disclosed that alkaline scrubbing of sewer atmospheres did the best job in removing stench-type odors.

The most complete odor removal was obtained with a 5 per cent sodium hydroxide solution in a packed column. Sodium carbonate solution was somewhat less beneficial. Lime slurries were also tested and proved to be of some value. A packed column proved to be more effective than a spray tower. Many other types of solutions were tried, but they did not improve the odor as much as the alkaline solutions.

Alkaline scrubbing solutions did not seem to be able to remove solvent-type odors present in some sewer atmospheres. Even when the sewer air had a predominant stench, after scrubbing with alkaline solutions a residual solvent odor was noticeable. This solvent odor, when present in small quantities, could probably be controlled by air dilution.

The use of packed columns presents many problems. Tall obvious structures are unsightly in a residential neighborhood and expensive to maintain. The pumping of even moderate concentrations of strong caustic solutions under pressure is hazardous and undesirable. Spray towers have all of the above problems, in addition to the plugging and corroding of the spray nozzles.

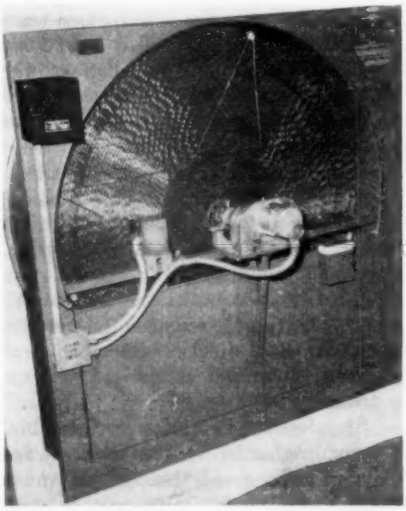


FIGURE 1.—Rotating screen humidifier used in industrial applications.

Consideration of these facts disclosed that a new approach was needed to the method of contact between the gas to be treated and the treating solution. This method should provide excellent contact with no pumping of the solution and preferably should be housed in a low building.

Rotating Screen

The air conditioning industry uses a rotating screen partially submerged in tap water to humidify and cool dry hot air. This presented an interesting idea for sewer odor treatment. The gases would impinge on the many wires in the rotating screen and the screen would be constantly wetted by the reacting solution in which it revolved. The solution tank could be filled and emptied by gravity, thus eliminating pumps and spray nozzles. A typical rotating screen humidifier used in industrial applications is found in Figure 1.

A small laboratory-scale model of a rotating screen scrubber was constructed. A wire mesh screen dipping into a reservoir of alkaline solution was continuously rotated and wetted

by the solution. The sewer gases were in contact with the wetted wire and the results obtained were similar to the packed column.

The next step was the construction and operation of a pilot unit, using three rotary-type evaporative coolers. Each of the coolers consisted of a 14-gal stainless steel solution tank and a bronze screen rotor. A high-torque, low-speed, motor-gear drive unit was included to revolve the rotor at 1½ rpm. The rotor consisted of alternate layers of flat and corrugated bronze screen wire wound as a rigid unit on a drum.

Stainless steel rotors were available, but required a 10- to 12-week wait for delivery. To avoid this delay, bronze rotors were used, although it was known that the bronze would corrode readily in basic solutions and in an atmosphere containing hydrogen sulfide gas.

In the pilot-plant setup, the rotary screen units were installed in tandem or series so the air would pass through each unit consecutively. The separate units were connected by sheet metal duct work. With this design, three different scrubbing solutions could be used consecutively on the same gas. A 14-in. diameter pipe connected the units to a manhole on a large sewer. A centrifugal blower was used to draw the sewer atmosphere through the rotary units and then discharge it through a short horizontal stack. Between the last unit and the blower, a flapper valve was installed to vary the air flow. Figure 2 shows a schematic odor scrubber using three rotating screens.

Application

In the tests made using sodium hydroxide alone, odor removal ranged from poor to excellent, depending on the number of rotors used, the strength

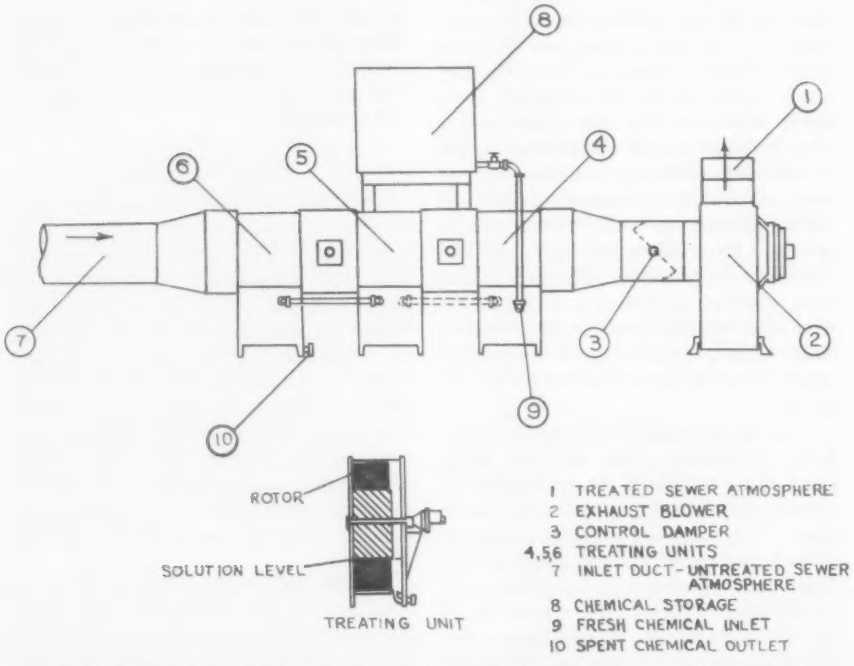


FIGURE 2.—Schematic drawing of an odor scrubber using three rotating screens.

of the alkaline solution, and the contact time or velocity of the gas.

The foul and putrefactive odors which are usually associated with sewers, and which are the major cause of complaints, seem to be successfully handled with strong alkaline solutions. The resulting odor, at best, is a mild musty one, and at worst it is a hydrocarbon solvent odor with eye-smarting characteristics. By moderate dilution, this solvent-type odor usually can be dispersed below the threshold of perception.

Using calcium hypochlorite (HTH) solutions in combination with sodium hydroxide gave fair results. Using strong hypochlorite solutions produced irritating and disagreeable odors in the fan outlet. In all tests except one using the hypochlorite, a sodium hydroxide solution was used after the HTH to absorb any chlorine in the gas. The use of hypochlorite alone (0.1 per cent solution) resulted in very little improvement, and in one test it seemed to make the odor worse. The use of chlorine compounds was not considered advisable if the treatment site were located close to a residential area. The irritating properties of these compounds might not be a deterrent in unpopulated areas.

The effects of three oxidizing compounds on the odors were investigated. Hydrogen peroxide, potassium dichromate, and potassium permanganate were tried in solutions of ½ per cent. None of these compounds seemed to be sufficiently effective to warrant further testing.

Sulfuric acid and phosphoric acid in concentrations of ½ per cent were tried in the last tank on several tests to remove any hydroxide carried over from the other units. During the time these acid solutions were used, sewer odors could be easily distinguished in the fan effluent. The acid wash in the third tank did not give as good treatment as tap water. The acid solution seemed to make more pronounced any odor components that had not been removed or were masked by the sodium hydroxide.

These results confirmed previous data that alkaline solutions are the best for sewer odor removal. The higher the pH of the scrubbing solution and the longer the contact time between the solution and the sewer atmosphere, the more effective is the odor removal.

The speed of reaction of the odor removal is apparently faster than the reaction between carbon dioxide and the sodium hydroxide solutions. Sodium hydroxide solutions lose their alkalinity mainly due to the carbon dioxide in the sewer atmosphere. Calculations based on the volume of air and the carbon dioxide concentration of the sewer atmosphere can be made to determine the theoretical neutralization of the sodium hydroxide solution. However, free hydroxide is still present in the spent scrubbing solutions after the odor is removed.

The next problem was to find the most efficient and economical treatment for the particular odors encountered in the sewers. The tanks were interconnected with piping so the treating solution would flow countercurrent to the air passing through the system. Fresh solution would be admitted to the unit next to the fan and after passing through each successive tank it would be discharged when it was spent. The sewer air would contact the weaker solutions at first and the strongest solutions at the end.

Methods of Determining Odor Removal

It is well-known that present methods of evaluating odors are crude. The use of a panel or group of observers appears to be the best method. The panel method and the reduction in hydrogen sulfide were used to evaluate most of these tests. Although hydrogen sulfide is only one of the many odor components in a sewer atmosphere, it is readily detected quantitatively by the Pomeroy method. Test-

ing for hydrogen sulfide reduction proved to be a good tool for measuring odor treatment when hydrogen sulfide was present in the untreated atmosphere. However, during several tests, when the untreated sewer atmosphere had a strong stench, no hydrogen sulfide was detected.

Several solutions were evaluated to determine their effectiveness in odor removal.

Evaluation of Solutions

Sodium Hydroxide Solutions

A 2-per cent sodium hydroxide solution, flowing through the tanks at a rate of 15 gph, removed 3 to 6 ppm of hydrogen sulfide from 800 cfm of sewer atmosphere. Residual hydrogen sulfide varied from 0.0 to 0.6 ppm. A musty burnt odor, not detectable as coming from the sewer, was observed at the fan outlet.

Using a 5 per cent sodium hydroxide solution at a flow rate of 20 gph, 6 ppm of hydrogen sulfide were removed from 1,000 cfm of sewer atmosphere. Only a trace of hydrogen sulfide was found in the treated air. The outlet odor had a mild burnt smell and was not offensive. This was considered to be the best treatment obtained during these tests.

Sodium Carbonate Solutions

Sodium carbonate, when used in a concentration of 6 per cent, proved to be moderately effective. The hydrogen sulfide concentration before treatment was 1.8 ppm and after treatment 0.0 ppm. The concentration of hydrogen sulfide at the time of the test was rather low. The sodium carbonate solution was flowing through the tanks at the rate of 45 to 55 gph, and 750 cfm of sewer atmosphere was being treated. Although this treatment produced noticeable improvement, a mild sewer odor could be detected at the fan outlet.

Lime Solutions

A saturated solution of commercial lime was used in treating 750 cfm of sewer atmosphere. The flow rate of the lime water was 60 gph. The hydrogen sulfide content of the air treated was reduced from 1.2 ppm to 0.6 ppm. A mild sewer odor prevailed at the fan outlet.

Tap Water

The use of tap water with no additives reduced the hydrogen sulfide content of the sewer atmosphere from 0.6 ppm to a trace on one test. An air flow of 800 cfm of sewer atmosphere was treated with 60 gph of water. A noticeable improvement was evident in the treated air, although it was considered to be insufficient treatment for most locations.

Masking Agents and Odor Counteractants

The addition of small amounts of commercial masking agents to the treatment solution proved to be an effective method of dispersing such compounds in the atmosphere. The largest amount that was used at any one time was 20 ml in approximately 45 gal of solution. This amount was judged to be too strong by observers at the fan outlet.

Cost

The cost of treating sewer odors by this contact method depends on three variables. They are the potency of the odor, the concentration of the solution, and the contact time required between the solution and the air to be treated. The potency of the odor, together with the amount of treatment required, controls the other two variables.

For minimum cost of operation, low concentrations of sodium hydroxide would probably give the most economical results. The rate of depletion of a 5 per cent sodium hydroxide solution in one test was 1½ times that of a 2 per cent solution.

Sodium carbonate and lime solutions, although not as effective as sodium hydroxide solutions, are cheaper and might find a use at some locations. The choice of the solution to use would depend on the degree of treatment desired and the intensity of the odor. Where there are large hourly fluctuations in the odor level, control of solution strengths or feed rates would help reduce the cost of chemicals.

Summary

The alkaline deodorizing of sewer odors with rotary evaporative coolers appears to have several advantages. The equipment can be completely installed in a low building as contrasted with the tall columns necessary for conventional scrubbing towers. Gravity flow can be used, thus eliminating the need to have alkaline solutions under pressure. The operation of the rotors is quiet. Additional contact time can be acquired by adding more rotor units. The equipment is comparatively inexpensive as it is mass produced for the air conditioning industry. The entire process could be set up to operate automatically either by pH control or constant flow.

Acknowledgment

The authors wish to thank the Bureau of Public Buildings and the Sewer Maintenance Division of the Bureau of Sanitation of the City of Los Angeles for their help in fabricating and setting up the component parts of this pilot plant.

FIRST-YEAR OPERATING EXPERIENCES AT SACRAMENTO, CALIFORNIA *

By Harold H. Jeffrey

Supervisor, Sewage Treatment and Pumping, Sacramento, Calif.

In starting a new sewage treatment plant of major size with a comparatively inexperienced operating crew, personnel certainly should be in line to have some experiences. Sacramento personnel did!

There was the inevitable operator who closed a plug valve against an operating plunger-type sludge pump. No, the shear pin on the pump did not break; a Dresser coupling on the 8-in. diameter raw sludge line opened, flooding the pipe trench with 50,000 gal of ripe sludge. There was the case of the break in the 2-in. diameter underground liquid chlorine supply line. And there was the night the operators spent riding on one of the floating-cover digesters during the first trial with high-rate recirculation for scum breakup. That was an experience, like standing on the lid of a pot of boiling rice 100 ft in diameter!

At the time, these experiences certainly were unpleasant, but something was learned from each of them in accordance with one dictionary definition of the work experience—knowledge gained from actually living through an event. This paper will be confined to a discussion of several of the more interesting situations at Sacramento and what was done to handle them.

Treatment Facilities

The tremendous diluting power of the Sacramento River permitted the design of a primary treatment plant with grit removal, comminution, preaeration, sedimentation, digestion, and vacuum filtration of sludge. Pre-chlorination and aeration are used for odor

* Presented at the 1957 Annual Meeting, California Sewage and Industrial Wastes Assn.; San Diego, Calif.; May 1–4, 1957.

control with post-chlorination for disinfection. Discharge of the final effluent is to the Sacramento River. All visible evidences of sewage are removed by the treatment plant, and the bacteriological and biological loadings on the river are kept within established limits.

Complete operational control of the plant is maintained by daily laboratory testing. Chemical tests made on the raw sewage and plant effluent include: pH, chlorine demand, alkalinity, sulfides, dissolved oxygen, BOD, grease, and syndets. Solids analyses include: settleable solids, suspended solids, dissolved and total solids, and percentage determinations of volatile solids.

Digester operation is checked by tests for pH, volatile acids, and alkalinity. Sludge feeding and withdrawal rates, temperatures, and gas production and quality are carefully watched. Tests are made on all sludge filtration processes for proper wash at elutriation, correct ferric chloride feed, condition of filtrate, moisture content of filter cake, and for filter drum efficiencies. Control is exercised on pre- and post-chlorination for proper chlorine dosage and residual. Bacterial checks are made on the plant effluent and on the river both upstream and downstream from the plant outfall.

The City of Sacramento has owned and operated its own sewage treatment system since 1878. The first sewers of record were brick and carried both domestic and storm flows by gravity to a steam pumping station which pumped into the Sacramento River. It was not until 1946, when plans were being made for the present sewage treatment plant, that separate systems for sewage and storm drainage were installed in new subdivisions.

The fact that most of the sewers in the older sections of Sacramento are of the combined type compels needless treatment of millions of gallons of air conditioning and lawn irrigation water. This is presenting an acute problem because flow through the plant is increasing each year. Although it is true that increased flows of air conditioning water to the plant are beneficial to the sewers in their flushing effect and dilution of the sewage, nevertheless there is a definite limit to the flow the plant can handle satisfactorily.

The population and industrial growth of Sacramento since World War II made it evident that river pollution from sewage wastes could no longer be tolerated. Therefore, plans were completed for a sewage treatment plant to serve the metropolitan area of Sacramento. Work on the treatment plant was started in December 1952 and completed in August 1954. The total cost of the project including six miles of influent and effluent sewers was $5 million. In addition to treating the sewage of the City of Sacramento, the plant processes sewage from areas surrounding the city, including the City of North Sacramento, the Hagginwood Sanitary District, County Sanitation Districts Nos. 1 and 2, and the Arden-Watt Maintenance District. These districts maintain their own pumping stations and pump directly into the Sacramento sewers with the exception of Sanitation District No. 1 which pumps into the treatment plant headworks.

Practically the entire industrial waste load placed on the plant comes from five large canneries. Since they all can tomatoes simultaneously, the highest plant loadings occur during the peak of this packing season, in the months of August, September, and October. Approximately 75 per cent of the annual load at the plant occurs during these three months. The volume of solid waste material from the canneries is controlled by requiring all packers to discharge their waste through the equivalent of 20-mesh screens before entry into the sewers. The strict enforcement of this requirement has taken a load off the plant which could become excessive.

The plant design anticipated a canning season flow for the year 1970 averaging 54 mgd, with a maximum

hourly rate equal to 76 mgd. A maximum channel capacity of 86 mgd was provided. The digestion system was designed to take expected maximum loadings of 80,600 lb of dry solids per day. During the 1956 canning season the average daily flow of raw sewage was 55.7 mgd, with a maximum hourly rate of 81 mgd. The average daily loading of dry solids received at the digesters during this same period was 60,000 lb.

In the combined system, flow is by gravity to two collection points called sumps. The combined storm water pumping capacity at these sumps is 580 mgd. The storm flow in excess of the design capacity of the sewage treatment plant is pumped directly to the Sacramento River at these sumps. Sewage is pumped to the treatment plant from the second of these two sumps through a 72-in. pressure line of spun concrete pipe. As this flow enters the headworks, a second flow is introduced at right angles through a 36-in. line from the Sanitation District No. 1 pumping station. The turbulence of the flow, combined with pre-chlorination at this point, caused a chlorine diffusion problem.

Headworks

The headworks structure contains grit removal equipment, flow measuring flumes, flow recording devices, and comminutors. Sewage entering the headworks is chlorinated to control odors, and then flows through four parallel grit chambers with a total hydraulic capacity of 86 mgd. When the rate of flow increases, additional channels automatically come into operation so that the maximum velocity (1.25 fps) is not exceeded. Conversely, when the rate of flow decreases, the number of channels in use is automatically reduced. Rubber-bladed collector flights pull the grit into screw conveyors for disposal by burial. The amount of grit received has been small, varying between 0.1 and 0.8 cu ft per million gallons of sewage.

Sewage flow is measured by four Parshall flumes and recorded continuously. The use of comminutors avoids the handling of unsightly screenings.

Sedimentation Units

There are five sedimentation units, each having duplicate tanks equipped with jet impingement air diffusers for preaeration, sludge collectors, sprays and scum skimming mechanisms, effluent launders, and sludge pumping equipment. Each tank is divided by baffles into three sections:

1. The aeration section located in the first 50 ft of the tank.—Nozzles diffuse air at a rate of 0.1 cu ft per gallon of sewage to float grease and oils, and to freshen the sewage, some of which has come from a distance of 13 miles. The detention time is about 30 min.

2. The skimming section.—Surface sprays use well water to push the floated grease and scum to rubber-bladed skimmers.

3. The laundering section.—The plant effluent, freed from floating material and solids, is drawn off the surface of the basin in troughs and discharged to the river.

The total detention time varies from 3.2 to 2.3 hr on an average and the overflow rate varies from 12,000 to 17,000 gal per lineal foot per day.

Sludge depths are measured by soundings to prevent accumulations which would gasify and float to the surface. Collected sludge is removed by plunger pumps on an automatic time cycle basis which is varied with the season of the year. Sludge collecting mechanisms operate continuously. Settleable solids removal averages 95 per cent and suspended solids, 55 per cent.

Digesters

The digestion unit consists of a central control building surrounded by five digestion tanks equipped with floating covers. Within the control build-

ing are the recirculation pumps, external sludge heaters, sludge metering equipment, and the complexity of pipes and valves necessary for regulating the sludge flows. Each digestion tank is 100 ft in diameter, has a 29.5-ft sidewater depth, and can hold 1,813,000 gal of sludge.

Raw sludge from the sedimentation basins is metered and pumped directly to the primary digesters after being mixed with heated, partially digested sludge which is being simultaneously recirculated through the sludge heaters. The heaters are gas fired and have a heating capacity of one million Btu per hour each. The sludge is constantly recirculated from the digesters through the heaters to maintain a temperature of 96°F. Since the solids content of the incoming sludge is about 3 per cent, large amounts of supernatant must be drawn off each digester daily to make room for additional sludge. The supernatant flows by gravity to the headworks.

The volatile matter in the raw sludge averages 75 per cent by weight. Gas production varies from a minimum in December of about 150,000 cu ft per day to a maximum of more than 700,000 cu ft per day during the heavy canning season in September; this is about 1 cu ft per capita. Gas is individually metered at each digester because its production is one of the most important indications of digester condition. The gas collected in the tank cover dome is taken off the top through flexible connections and brought down the exterior of the tank to meters.

During the first year of operation, three of the five digesters were used as primary tanks and two as secondary tanks. It was soon evident that direct elutriation and vacuum filtration of digested sludge from the primary tanks was feasible, and posed no odor problem in the open elutriation units. The sludge filtered well with no increase in the amount of conditioning chemical (ferric chloride) required. The solids loadings of the digesters permitted good digestion as evidenced by the 40 per cent volatile matter content of the primary digested sludge. The secondary digesters are being used as "scrubbing" tanks for the supernatant prior to its return to the headworks.

Sludge Filters

Dewatering of the primary digested and elutriated sludge is accomplished by means of vacuum filters. The sludge is made to filter more readily by the addition of about 2 per cent ferric chloride per pound of sludge on a dry weight basis. Ferric chloride is relatively expensive and its use is kept at a minimum by completely washing and decanting all incoming sludge prior to chemical dosage. Elutriation consists of washing each volume of sludge twice in three volumes of water. Plant effluent is used in the washing process. The effectiveness of the wash is evidenced by the reduction in alkalinity of the sludge. The alkalinity of the digested sludge is reduced on elutriation from 2,100 ppm to 475 ppm on the first washing and to 275 ppm on the second washing.

Ferric chloride is delivered to the plant in 3,500-gal lots by tank truck and is stored in a rubber-lined tank. Dosing is regulated by the operator's visual inspection of the sludge. It has been found that in day-to-day operation the actual appearance of the filter cake on the drum is the best criterion of correct dosage of ferric chloride. A shiny cake indicates too little ferric chloride and a dull colored cake with streaks of tan indicates too much. The so-called vacuum break test requires too much time for routine control. However on special occasions when difficult sludges are encountered, the vacuum break test is used to establish that the ferric chloride dosage is correct for the given sludge and that the trouble is elsewhere.

The first filter cloths were of wool and failed completely after 39 and 70 hr of use. Replacement cloths of wool, however, gave more than 1,000 hr of

service and seemed reasonably satisfactory. Upon hearing the merits of Dacron cloths, the filter medium was changed and one Dacron cloth now has been in use 1,350 hr with no sign of fiber failure. Cloths are washed at the end of each day's run with a cold water spray at 40 psi. Once a week each cloth is given a detergent wash * to loosen oil and grease from the cloths. Accumulations of iron in the cloths are removed when blinding begins to occur by revolving the drum with cloth in place for 6 hr in a 10 per cent solution of inhibited muriatic acid. This is followed by an equal number of hours in a cold-water wash.

The vacuum filters presently produce a maximum of about 40 cu yd of filter cake per day using one shift five days per week. The cake has a moisture content of 65 per cent. The City of Sacramento is not attempting to market this material, but is giving it away for the taking as a gesture of good-will. Large quantities of the cake have been used by local nurseries, ranchers, and the city on its parks and golf gourses.

Chlorination System

The chlorination system is one of the most interesting features of the plant. Liquid chlorine is received at the plant by rail in 30-ton tank cars and is transferred as a liquid through a 1,300-ft underground line to the chlorination building. Dried compressed air can be used to move the chlorine through the line. Also provided is a 40-ton liquid chlorine storage tank which may be used to store chlorine adjacent to the chlorination building. Three chlorinators with capacity of 6,000 lb per day each are installed in the building. Provision has been made for two more units. At present two units are used for pre-chlorination odor control and one for post-chlorination disinfection. Pre-chlorination is practiced the entire year, the dose varying from a maximum of 18 ppm to a minimum of 3 ppm. Post-chlorination is employed from May through October when the Sacramento River receives most of its recreational use; the dose varies from 1 to 3 ppm. All post-chlorination dosages are based on the amount of chlorine necessary to maintain a coliform count in the river below the plant outfall equal to or less than that above the outfall.

The 1,300-ft liquid chlorine line is of 2-in. black welded steel pipe (Schedule 80). Little trouble has been experienced with this line in nearly three years of service. Although two failures have occurred, one a defect on the interior of the pipe due to manufacturing and the other a bad weld, examination of cut sections of the piping near these breaks showed it to be as clean and free from corrosion as the day it was installed.

The tank cars of chlorine are delivered under a "car board lease" agreement with the city and practically no demurrage is applied. It has been the practice for over two years to draw the chlorine off through the chlorinators directly from the tank car. Duplicate railroad spurs permit a quick switch from an empty to a full car at change-overs. There is no weighing scale in connection with the unloading facilities; chlorine is withdrawn until the pressure is reduced to 15 psi or less. Stoppage of liquid chlorine flow from the car is observed visually through a sightglass on the line.

Connection of the tank cars to the chlorine line is made with a 1-in. copper tubing fashioned into a flexible loop between the car and the line. The original plant installation of stainless steel flexible hosing failed after unloading two cars. Although the number of cars the copper tubes would unload before failure has not been determined, they are used only eight months to prevent possible metal fatigue. Excess flow-type check valves protect against unloading of the 1,300-ft supply line in event of rupture in the copper tubing connection. This is

* Ultrawet 60L.

necessary since the 2-in. chlorine line contains over 2,400 lb of liquid.

Operating Problems

Pre-chlorination

One of the early problems during the first year of operation was that of obtaining proper distribution of chlorine at the point of pre-chlorination. The chlorine diffusers are located at the headworks in a chamber where the flow from the 72-in. influent sewer rises vertically before being distributed horizontally through four grit collecting channels. Slightly below the diffusers, and at a 90° angle to the upward flow from the 72-in. line, a side flow is introduced to the inlet chamber from a 36-in. sewer.

During the first six months of operation, while awaiting the completion of the piping connection between the Sanitation District No. 1 pumping station and the plant headworks, no sewage was received through the 36-in. line. Some difficulty had been experienced during this early period in getting proper distribution of chlorine through the grit channels, but this appeared corrected by changes made in the diffuser manifold.

However, as soon as flow was received through the 36-in. line, poor distribution of chlorine became apparent to a considerable degree. The diffusers consist of 6-in. cast iron, rubber lined pipe with 1-in. diameter holes spaced 6 in. apart. The diffuser piping is L-shaped as placed in the inlet riser chamber; this gives both vertical and horizontal distribution of the chlorine solution. All distribution occurs above the junction of the inlet of the 72-in. and 36-in. lines and in the upward flow section of the inlet chamber.

In checking the cause of the poor distribution of chlorine it was found that most of the chlorine solution was going to the east channel or in the direction of the side thrust from the 36-in. line. This unusual situation resulted in the presence of free chlorine on the east side of the chamber and hydrogen sulfide from unchlorinated raw sewage on the west side of the same chamber. This uneven distribution was further magnified in its effect on the large sedimentation tanks immediately following the grit channels. The unchlorinated raw sewage in the west channel flowed into the west basin. This long uncovered basin provided an ideal situation for dispersing the hydrogen sulfide to the atmosphere. The effect on the neighborhood can be readily surmised.

Some type of baffling arrangement was apparently needed, preferably an adjustable or movable one to take care of variations in flow. Such a piece of equipment was already installed in another part of the plant; at the point of post-chlorination a flash mixer had been installed to provide rapid contact between the chlorine solution and the effluent. The unit had a long shaft, and the paddle was covered with rubber for protection against the chlorine solution. It appeared to have possibilities as an adjustable baffle when installed in the headworks inlet riser chamber.

This unit was moved to the headworks on an experimental basis and proved so successful that its use there is being made permanent. By rotating the mixer counterclockwise at varying speeds, the flow pattern at the riser chamber could be completely reversed and all the chlorine solution could be directed to the west channel instead of to the east channel. By finding the correct speed of rotation for a given flow, enough reversal could be produced to give a good distribution of chlorine solution in all four grit channels. During low flows from the 36-in. line, it is not necessary to run the mixer. At high flows the mixer is run continuously at about 10 rpm in a counterclockwise direction.

Proper distribution of chlorine is checked hourly on a 24-hr basis by the operators. For odor control during the warm months of the year, an orthotolidine chlorine residual is maintained

throughout the entire length of the sedimentation basins. This is necessary because of the location of the plant in a residential area. The carrying of a free chlorine residual to the point of post-chlorination accounts for the very low post-chlorination dosages of 1 to 3 ppm. The chlorinators respond to any change in flow automatically. Any increase or decrease in the dose itself has to be set manually by an operator; this dose is then fed automatically to any rate of flow received at the plant.

Plant Location

The unusual location of the Sacramento sewage treatment plant in the center of a fine residential area has made attractive appearance, careful operation, odor control, and noise abatement of the utmost importance. When the site of the plant was selected in 1949 it was the last large piece of property near enough to the city to make the cost of influent lines economically feasible and still be located near enough to the Sacramento River for the effluent lines. The good soil formation permitted construction of foundations without piling. In addition, it was adjacent to the pumping station of Sanitation District No. 1 where another 20 acres could be obtained for future expansion of the plant, together with the 40 acres of the plant site itself.

At the time of purchase, the site was fairly isolated so far as homes were concerned. Directly south of the plant was dairy land with but a single house in 380 acres. When the plant site was still under consideration the city limits were a mile away. By the time construction on the plant was underway annexation had moved the city limits to the plant site, and by the time construction was completed additional annexation had moved the limits one mile beyond the plant. The former dairy farm had been developed into an exclusive subdivision with lots staked out and sold right up to the plant fence for as much as $4,500 apiece. Now, since the plant has actually been in operation more than a hundred homes, many in the $25,000 to $35,000 price range, have been built around the plant. It is a constant challenge to operate and maintain the plant in such a manner that the confidence of these home owners in locating nearby is justified.

Appearance

The first prerequisite for living unobtrusively with neighbors is an attractive appearance for the plant and the operating personnel. No matter how well-operated a plant may be it is difficult to convince outsiders of the fact if the buildings need painting, the equipment is dirty, the grounds weedy, and the operators look like bums in nondescript clothing. At Sacramento the plant buildings have been designed along low modern lines with pleasing colors which blend into the surrounding grounds. The entire 40-acre site has been landscaped to give a park-like appearance with extensive lawns, shrubs, and several large plantings of massed flowers. By a fortunate arrangement, all responsibility for the upkeep of the plant grounds is vested in the Park Department. There is thus no need to take a laborer away from plant operation to weed shrubs or water lawns, nor do the plant grounds become neglected as so often happens.

Operators are required to wear white uniforms at all times except when engaged in work that is particularly messy, then blue coveralls are used. The uniforms are white with blue trim, and have the City of Sacramento emblem sewn on the front. These uniforms are cleaned and kept in repair by a local laundry service; the city pays the bill. The treatment plant had been in operation some time before these standard uniforms were adopted. It was gratifying to see how much more interest the men took in their personal appearance after the advent of the uniforms. With the exterior of the plant neat and attractive it was not at all difficult to get the op-

erators to match this with good housekeeping within the buildings.

Odor Control

Of course a sewage plant could look like a rose but not smell like one. Another requirement for living happily with the neighbors involves the most careful operation to prevent odors and objectionable noise. Heavy reliance is placed on pre-chlorination to prevent odors in the open settling basins. This requires constant vigilance 24 hr a day. There are complaints within an hour during hot weather, if the chlorine supply fails. Likewise there is trouble from odors within a matter of hours at any time of the year if it becomes necessary to put any of the open sedimentation basins out of service. It is necessary to dewater the basin immediately, no matter what time of night or day, and to hose down all walls, underwater piping, and launders as the basin is emptied. Since each side of one of these basins contains 750,000 gal of sewage which must be pumped out, this is no small task.

It has been learned that a lot of small odors can add up to a rather big odor, and consequently much attention is given to the sidewalls or corners of channels where coatings may accumulate. High-pressure hot water (400 psi) is used to clean stubborn build-ups of grease on walls, piping, and equipment throughout the plant. Hosing down all effluent launders once each shift keeps these sources of odor under control.

The escape of gas in the vicinity of the digesters may become objectionable. Maintenance of correct pressures in the domes of the floating covers and at the waste gas burners prevents cover instabilities with canting of the cover and loss of gas at the water seals. The condition of the diaphragms on the gas pressure relief valves at the covers is checked often for signs of rupture, another source of gas loss.

One persistent source of hydrogen sulfide odor during the initial months of plant operation was the raw sludge pit where all the sludge pumped from the sedimentation basins is checked visually for thickness before being pumped to the digesters. The building in which this pit is located had a considerable odor problem because the ventilating fans discharged to the outside. Odors from the raw sludge were very noticeable in the vicinity. Effective control of the odor problem was achieved in a rather unusual way. Since this building also housed the blowers which furnish the air for the pre-aeration system, it was possible with a slight change in piping to reverse the ventilating process. Air from within the building is now pulled into the blower intake and forced into the sewage at the sedimentation tanks through the aeration system. All odors originating within the building are thus absorbed in the sewage flow. After two years of this service, one of the blowers was torn down and examined for the effect of hydrogen sulfide on its aluminum impeller; there was none. The welded steel air ducts leading to the aerators were also examined later and found to be in good shape.

Noise Control

At the start of operation in 1954, many complaints were received from residents within a three-quarter mile radius of the plant of pulsating noises during the quiet early morning hours. The source of this noise was found to be the sludge heaters whose exhausts got out of synchronization and produced the pulsating effect. Maxim silencers were placed on these units where the exhausts extended through the roof of the control building. It would now be possible to sleep on a cot within 10 ft of the building without annoyance from noise. At the same time, silencers were also put on the four blowers when these were rearranged for the sludge building ventilation system. All gasoline driven pumps

and cleaning equipment are run only during daylight hours in deference to the many hundreds of people sleeping within earshot of the plant.

Public Relations

Good public relations are also fostered by encouraging civic groups and school classes to visit the sewage treatment plant. A meeting room designed specifically for such groups has been built into the administration building. This room contains a 6- by 8-ft colored aerial view of the plant. A matching flow chart is used to explain the functions of the plant to visiting groups prior to a tour of the plant itself. Dinners have even been served in connection with meetings at the plant to further emphasize the pleasant conditions. A 12-page brochure with many pictures and a descriptive text of the plant has been published and is handed out to all visitors.

Digester Operation

Start-up

One of the first problems faced in getting the plant underway was that of digester start-up. The construction specifications required that all structures holding water were to be tested first with the plant water supply before the admission of sewage. Several weeks before the acceptance of raw sewage the digestion tanks were filled with test water. Heating of the three primary digesters, using auxiliary natural gas, began at once. This gas has not been used except during the break-in period; although it is still obtainable as a stand-by.

Temperature of the water used in testing the digesters was 60°F when heating began, and in 12 days it was raised to 90°F. Sludge was not fed until the temperature reached 90°F. Minor equipment malfunctions occurred and adjustments were made, but these were corrected without much loss of heat.

At the start all three primary digestion tanks were fed raw sludge; however, the feed to one tank was soon stopped and 100,000 gal of seed sludge was obtained from Stockton, Calif., 45 miles away. One month after the first sewage was received seeding was started to the No. 5 primary digester. Two tank truck and trailer combinations carrying 6,000 gal were used and the seeding was completed within two days. The bottom material was recirculated to the tank dome or top. This was in addition to the normal continuous recirculation from a higher supernatant level to the dome. Upon completion of the seeding operation, feeding of raw sludge to the digester was again started at a rate equal to 10 per cent of the tank contents on a dry solids basis. The two other primary digesters received no seed sludge during this period and were fed raw sludge on the same basis as the No. 5 digester.

The volatile acids picture comparing the seeded and unseeded digesters is most revealing. On the 10th day of sludge pumpage to the unseeded digester the volatile acids concentration had already reached 1,500 ppm. Acid production increased steadily to a peak of 3,200 ppm, 40 days after feeding started. The feed rate during this period was between 5,000 and 10,000 lb per 24 hr on a dry weight basis. In contrast, the volatile acids content in the seeded digester increased prior to the addition of seed sludge at the end of the second week of operation. Upon the addition of the seed sludge the acid content decreased rapidly and leveled out at about 200 ppm within three weeks. It was almost three months before the volatile acids content in the unseeded digester decreased to less than 500 ppm.

As soon as seed sludge was available and could be spared, it was transferred from the seeded digester to the unseeded ones. The pH of the unseeded digesters varied from 4.9 to 7.0 when normal digester operation was achieved. Alkalinities increased from a low of

750 ppm to 1,900 ppm during the same period.

Comparing the results obtained in these two digesters, it is readily apparange; gas of usable quality was availwhile. The seeded digester was in full operation within one-third of the time necessary to start the unseeded digester. There was no rise in volatile acid production above the 2,000 ppm range; gas of usable quality was available much earlier. The cost for trucking the seed sludge was approximately $1,000 and considered to be money well-spent.

Recirculation

Provision was made for high-rate recirculation of the digester tank contents at the supernatant level for the control of scum. Recirculation rates were planned for a theoretical turnover of the digester volume in an 8-hr pumping period. Two 10-in. connections were installed in each digestion tank. A portable 4,000-gpm gasoline driven pump can be placed alongside the digester to take the warm supernatant at a low level and discharge it just below the floating cover into the scum area. The pump discharge is inclined 30° to give a rotation counterclockwise to the recirculation effect in the tank.

This type of recirculation has now been used experimentally for two full seasons in reducing the scum blankets in the digesters. Scum layers which had built up to depths as great as 8 ft have been consistently reduced to 2 ft with this method. So satisfactory have been the results obtained with the portable pump that a permanent manifold system of pipes and valves has been constructed to permit recirculation of any digester with a single electrically driven pump. With this permanent recirculation system it is expected that accumulations of scum will be worked on continuously and prevented from reaching a thickness in excess of 2 ft.

In the process of breaking scum experimentally with the portable pumping unit, an interesting fact became apparent. The greater the elapsed time after the end of the canning season before recirculation was started, the greater was the number of hours of pumping required to break up the scum. Two of the primary digesters which were recirculated within six months after the end of the canning season required 139 and 145 hr of pumping for scum reduction. A third digester was recirculated for 375 hr with no result when recirculation was attempted eight months after the end of the canning season. However, at the end of the ensuing canning season the scum was broken up using the recirculation system.

With the new permanent recirculating piping and electric pump it is planned to use essentially the same technique for scum breakage that was employed with the portable unit. No attempt will be made to recirculate during the actual canning season of August through October. A previous experience of recirculating a digester with an active canning load and 8 ft of scum met with near disaster when the digester went into an intense state of activity approaching foaming.

It will be possible under the new setup to recirculate more than one digester at a time. The total number of hours needed to reduce scum may be lessened since it will be possible to pump 24 hr per day with the electric motor. The gasoline driven equipment had to be limited to the daylight hours because of the nuisance of engine noise in this residential location. The digesters will be fed sufficiently to maintain gas production at a high level. The floating cover will be raised and lowered during recirculation so that the pump discharge will be at different depths of scum. When digestion of the scum begins, gas production will be watched on an hourly basis. Feeding and recirculation will be altered if the gas production and activity of the tank appear to be getting out of control.

Personnel

As stated earlier in connection with the upkeep of the sewage treatment plant grounds by the Park Department, the policy of the city of specialization in regard to the work done has proven very satisfactory. This same specialization is employed in the complete separation of the mechanical and electrical equipment maintenance from plant operation.

The maintenance section of the Division of Water and Sewers has the responsibility for all maintenance work in both the water and sewage treatment facilities. The many crews of machinists, electricians, welders, and painters are headed by a supervisor of maintenance who works with the supervisor of sewage treatment in establishing priorities for needed maintenance and in setting up preventive maintenance programs. One crew is stationed at the sewage treatment plant for routine maintenance, but in the event of special jobs or emergencies as many as three or four additional crews are available to push the work to completion quickly. Recently a main collector chain in one of the sedimentation tanks jumped its sprocket in a 250-ft run, broke nearly half the redwood flights, and damaged the chain and air piping. The plant operating crew immediately dewatered the basin and the maintenance section moved in with several crews. The broken flights were replaced with new timbers and the damaged chain and air piping were repaired. What at first appeared to be a job of a week or more took only a matter of hours with the specialization of personnel and operating forces. Having trained men work on special equipment has paid off in the small amount of time lost due to mechanical and electrical shutdowns. Plant operators are responsible for the correct operation of all equipment, proper lubrication, the reporting of mechanical or electrical troubles, the keeping of records, and the sampling for the laboratory.

The plant has a staff of 27 men including a supervisor, a chemist, an assistant chemist, 21 operators, and 3 laborers. The supervisor directs the general operation of the plant and the chemist acts as his assistant and manages the laboratory. All operators are responsible to a supervising operator, and each shift of operators has a chief operator or shift boss. Operators work 8-hr shifts with a schedule of five days on, two days off, then four days on and two days off. Rotation of shifts is not used but operators do have a choice of shifts according to seniority when vacancies occur.

A rotation plan for familiarizing personnel with the various operations is in effect. After having become experienced in one unit of the plant an operator is moved to another part. This plan works to the advantage of both the operator and the city. The operator does not tend to become "stale" in working too long at one station. He has a better insight of what is happening in other parts of the plant. The city gains in increased efficiency of the operators and in being able to have any operator step in to operate any unit of the plant if the occasion arises.

All operational orders are written and posted on bulletin boards in the respective work areas. A plant manual of operations has been compiled which explains in detail plant procedure for all personnel. It discusses to whom they are responsible, what they are expected to do, how it should be done, and why it is important that it be done right.

Conclusion

Although there is nothing unusual about the Sacramento sewage treatment plant, it is an outstanding plant in its ability to function without a nuisance in the center of an exclusive residential area. It was successfully placed in operation without a major incident and is doing an effective job.

WHIRLING DERVISH STOPPED

By Cedric Webster

District Manager, Menlo Park Sanitary District, Menlo Park, Calif.

Rotation of the floating cover on the secondary digester by the wind caused occasional failures of the flexible gas connection, due to the strain of rotation. Two 55-ft diameter digesters of the Menlo Park Sanitary District, Menlo Park, Calif., are each equipped with a floating cover. One digester is operated as the primary unit and the other as the secondary. Absence of a scum layer on the secondary digester has permitted the cover to turn with the prevailing wind. Tying it was impractical because sufficient slack would have to be allowed for variation in the cover height, and only a few degrees of rotation would throw a strain on the flexible gas connection.

The device the plant operators evolved was simple and effective. Two 1½- by 1½- by ¼-in. steel angles were welded to each side of a ¼-in. steel plate. The angles were long enough to reach from the top of the digester wall down to and astride the cover corbels. The whole assembly was slipped down along side the digester-cover roller and fastened to the digester wall with two ½-in. cap screws (Figure 1).

The steel angles are spaced about 2½ in. farther apart than the length of the steel bumper-rollers which are part of the cover itself. The action of the rollers has not been impaired in any way, and the cover is still free to move up and down. When the cover starts to turn, the side of the roller comes into contact with the steel angle, thus further rotation is prevented. Two assemblies mounted on opposite sides of the digester are entirely adequate.

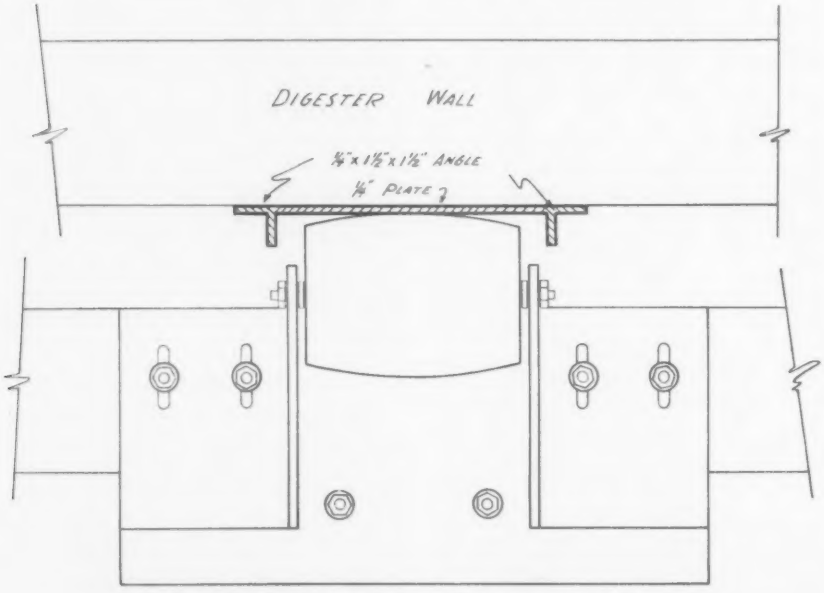


FIGURE 1.—Device to stop digester cover rotation.

THREE-YEAR SUMMARY OF OPERATION, BLASDELL, NEW YORK, SEWAGE TREATMENT PLANT*

By Stanley J. Pieczonka

Chief Operator, Sewage Treatment Plant, Blasdell, N. Y.

The industrial Village of Blasdell, N. Y., is served by a modern 0.75 mgd sewage treatment plant constructed in 1951 to replace an overloaded Imhoff tank and standard-rate trickling filter plant. To remodel this plant would have cost a minimum of $250,000, whereas a new plant was estimated to cost $450,000. Through the financial cooperation of the industries located at Blasdell, the village was able to finance the new plant without exceeding its bonding limit.

The new plant serves the Village of Blasdell (3,500 persons), the Sagamore-Osborne Heights section of Hamburg, N. Y. (1,500 persons), the Ford Motor Company stamping plant, and a manufacturing unit of the Bethlehem Steel Company. The two industries employ 3,500 and 200 persons, respectively. All sewage is pumped to the treatment plant through a 14-in. force main, in which the flow of the two lift stations is combined.

Complete treatment of the sewage is provided by two-stage high-rate filtration. Primary and secondary digesters and sludge drying beds are provided for handling the sludge. The metered influent sewage flows through grit chambers to the rectangular primary sedimentation tanks. Sludge is withdrawn through telescoping valves and pumped to the primary digester.

Settled sewage flows through the first-stage high-rate filter and then to a distribution chamber and the inlet of the second-stage high-rate filter. Each filter is 45 ft in diameter. Recirculation to the first-stage filter is at the rate of 500 gpm, whereas the second-stage filter receives 1,000 gpm of recirculated effluent from the final sedimentation tanks. All recirculated flow is pumped, and secondary sludge is returned to the raw sewage. The piping and pump system is extremely flexible and permits various recirculation rates and flow combinations. The rates of 500 gpm on the first-stage filter and 1,000 gpm on the second-stage unit appear to be the most effective for present operations.

Insufficient construction funds forced the elimination of the grit removal chamber. After two years of operation a large quantity of material accumulated in the primary sedimentation tanks and the primary digester. Dewatering the sedimentation tanks revealed the complete clogging of the sludge collection hopper. The tanks were cleaned and a temporary steel grit chamber was installed.

Grit removal has been satisfactory and no further problems have occurred. All grit is pumped to the sludge drying beds and immediately covered with digested sludge. Odors usually associated with grit removal have thus been kept to a minimum.

Digesters

Scum developed to a depth of 6 to 8 ft in the two digesters. No serious problem was encountered with the scum in the secondary digester, because the tank is open and used only for sludge storage. However, the primary digester is equipped with a floating cover and considerable difficulty developed due to excessive tipping of the cover as a result of the scum and trapped gas. The tipping caused the gas line to crack and it filled with supernatant liquor.

Immediate repairs were necessary.

* Presented at the Spring Meeting, New York Sewage and Industrial Wastes Assn.; Lake Placid, N. Y.; June 17–18, 1957.

A lagoon was constructed and digested sludge was pumped into it from the secondary digester. Then all of the primary digester sludge and a portion of the scum were transferred to the secondary tank. Repairs were made to the gas line and the broken piping was replaced.

The scum in the digester still posed a problem, as removal by existing methods was impossible. The open secondary digester was continued in use and received raw sludge. Following inquiry into methods of scum removal, the use of compressed air was chosen. The digester was filled with plant effluent and pipes were pushed through the floating scum to the bottom of the tank. Using two compressors, air was forced into the digester for about three days. At the end of this period the scum was sufficiently broken up and liquified to permit pumping to the sludge lagoon. The grit accumulation was washed to the sludge withdrawal line.

After the first digester was completely cleaned of all grit and scum, sludge was transferred from the middle of the secondary digester to serve as seed. All scum and grit were removed from the secondary digester in a similar manner. The dry portion of the scum took four days of continuous application of compressed air to break it up sufficiently for removal.

Industrial Wastes

With the conclusion of the mechanical work on the plant, attention was directed to analysis of the industrial wastes. The determination of the characteristics, strength, and sources of these wastes was important because the filters became completely septic at times and gave off obnoxious odors. Routine plant tests revealed that the raw sewage had a high BOD.

By consolidating the laboratory equipment of the nearby Lackawanna sewage treatment plant with that at Blasdell, it was possible to amass sufficient equipment to conduct 24-hr studies of the raw sewage. Extra manpower was obtained for sample collecting, and fresh reagents were prepared.

By using two steam baths and a 103°C oven, a quick turnover of total solids dishes and suspended solids crucibles was possible. This enabled immediate re-use after the dishes and crucibles had been washed, dried, and weighed. The BOD determinations were limited to two bottles per sample because of insufficient incubator capacity. Reagents were added, using burettes.

The 24-hr analysis of the wastes from the Ford Motor Company stamping plant showed an influx of industrial wastes detrimental to plant operation. On the basis of these tests, meetings were held with village officials, health department representatives, and the company management in an effort to reduce or prevent the flow of toxic wastes.

The plant is rather large, and finding the source of the wastes proved to be difficult. However, by determining the time it took for sewage to flow to the pumping station and knowing the collection time of the samples, it was possible to estimate quite closely the time when the waste entered the system. By relating this time to the approximate time of certain manufacturing operations in the stamping plant, an investigation was made of these operations. Some of the wastes were highly colored, thus aiding the work of tracing the source. As a result, the wastes were eliminated, and a subsequent analysis of the effluent four months later showed a marked decrease in the detrimental wastes.

Continued cooperation between village officials, health department personnel, and the various industries and business establishments is necessary. The problems of industrial wastes still continue, due to new and different wastes, although they have been reduced con-

siderably. Serious plant overloads should not occur now as they did in 1954.

Lift Station

Priming problems due to leakage of the pump packing at the Blasdell pumping station have been overcome by installation of new shaft sleeves and a water injection unit for packing lubrication. Pump priming is done by an automatic vacuum priming system. The use of water lubrication has reduced packing wear, pump leakage, and vacuum priming failures.

Constriction of the float control by an accumulation of grease in the float tube has necessitated periodic cleaning of the tube with a steel plunger. However, the possibility of an unexpected malfunction always remained. To overcome this difficulty, a special float was constructed which would have more clearance between the float and the float tube wall. In addition, a separate float system was installed in the bar-screen chamber of the pumping station. This installation consisted of three separate floats which activated the three largest pumps in the event the main float failed. These floats have been set low enough to prevent flooding of the lowest sections of the village.

Plant Grounds

One of the final phases of plant rehabilitation has been improving the aesthetic values of the landscaping at the treatment plant and the main pump station. The ground surrounding the main plant units and control building was plowed and disked, and fertilized for better grass production. Each year two additional flower beds are prepared. At present there are three large beds filled with canna lilies and four smaller beds for hardy annuals. Approximately 1,500 plants are set out each spring at the plant.

The pump station grounds were landscaped by filling and leveling. A nice lawn has been developed and a large flower bed has been planted. The road to the station has been curbed and paved.

Hardy annual plants are used almost exclusively, except for a recently-started rose bed. The annuals bloom until frost and require a minimum of attention. All of the flowers are propagated in the control building and set out in a coldframe until planting time. The recent installation of an electric heater in the coldframe will enable much earlier propagation of the flowers.

Landscaping requires a large amount of time and labor; therefore, the plan is for extension of lawns and flower beds on a piece-by-piece basis until the work is completed.

Acknowledgment

The encouragement and assistance of the many individuals who aided the author during the period of initial operation are sincerely appreciated.

TIPS AND QUIPS

Accident Reports Needed

Four construction workers were burned, two seriously, in a sewer gas explosion at a subdivision project in Bloomington, Ind.* Is anyone keeping a running record on the mortality associated with work in sewers and sewage treatment plants? A number of fatalities and near-fatalities have been reported in the Operator's Corner during the preceding 12 months. The cases reported are probably only a small percentage of the total number of incidents occurring annually. No sys-

* *San. Engrg. News*, Dec. 1957.

tematic effort has been made to locate all such occurrences. Let this be an appeal that during 1958 all readers of the Corner send in, by postcard or otherwise, a brief account of any sewer or sewage treatment plant accident that comes to their attention—whether it occurs in their town on in their state. We will try to gather some statistics.

Flow Timer *

A simple method for checking the flow through a sewage lift station is to wire a self-starting electric clock into the pump circuit. The clock is set at 12; then when the pump operates the clock runs, adding up the hours and minutes. A simple multiplication of pump capacity times hours and minutes gives the flow during the check period. Remember that only periods of less than 12 hr of pump operation can be recorded, and one clock is needed for each pump in multiple-unit lift stations.

This method of checking the operating period of pumps can be applied to other pieces of electrical equipment in a similar way.

Reduced Spark Potential

Tools used where sewer or digester gas is a hazard can be coated with neoprene paint to reduce the danger of sparking. A good paint distributor can answer your questions on neoprene paint–or write to the E. I. du Pont de Nemours Company, Wilmington, Del.

Water Conservation

Water conservation will reach into every home served by plumbing with the introduction on the market of a double valve flush unit for the toilet flush tank. An upward movement of the flush lever provides for a "half-flush," thereby reducing water consumption by 50 per cent. Since the average flush tank uses about 5 gal of water, there is a saving of 2½ gal per flush. The regular full-flush is selected by pushing the flush lever down.

By reducing waste water to a minimum, sewage pumping and treatment costs could be lowered and the capacity of plants greatly increased. An appropriate slogan might well be "up to conserve," rather than "dilution is the solution to pollution." However, such a panacea for the overloaded sewage treatment plant does not appear to be imminent.

Packaged Trickling Filter Plant

Several equipment manufacturers have marketed packaged activated sludge sewage treatment plants for small installations. Also, a number of consulting engineers have designed activated sludge or trickling filter plants for situations where the population served is small. Now, a manufacturer of sewage treatment equipment has announced the availability of a compact, fabricated trickling filter plant to handle 13,300 gpd. A high degree of treatment should be provided by the unit,† which consists of two-stage filtration and clarification. Sludge is handled in an unheated sludge digestion compartment.

Units of Expression

Superintendent I. G. Knoebel, Belleville, Ill., is one of the few operators to comment on the new units of expression (THIS JOURNAL, **29**, 2, 134; Feb. 1957). He reports that he is using the units in his monthly reports and has found them to be an easy and understandable approach to the problem of expressing plant data on a "universal" basis.

The comments of other operators who have given the new units a try will be welcomed.

* From *The Filter*, by Wm. M. Wright, Hollywood, Fla.

† CompleTreator, Dorr-Oliver Inc., Stamford, Conn.

Editorial

1957 GROWTH IN MEMBER ASSOCIATIONS

The January issue of this Journal noted the favorable action of the Federation Board of Control at its Boston Meeting, October 6, 1957 on petitions for membership by four new Member Associations.

The new U. S. Associations are the Utah Sewage and Industrial Wastes Association and the Mississippi Sewage and Industrial Wastes Association. With these, there is the geographic satisfaction that 47 of the 48 United States are now included by Member Associations. The remaining state, Nevada, has made inquiry as to the possibility of becoming a new Member Association, thus there is hope that this state will be included as a Member Association within the early future.

Outside the United States, the addition of the New Zealand Sewage and Industrial Wastes Association and the Israel Association of Sewerage Engineers include two distant areas where the importance of sewage and industrial wastes treatment has been on the increase in recent years.

To all of these new Member Associations and to all of their members, we bid a hearty welcome to Federation membership. We hope all new members will be well served by their new affiliation locally as well as by the international Federation. While the Federation is an organization of organizations, each person with a membership tie should feel a real part of it and partake fully of membership advantages.

Members of Federation Member Associations can certainly take pride in the increase in Member Associations of over 10 per cent in one year—from 38 to 42. Certainly new Associations are by their nature limited in membership numbers, but it appears that the combined membership of these new organizations may reach 150 before the close of 1958.

The original committee of One Hundred, and all of those who have served the Federation from its beginning can take just pride in this further expansion of the organization. When the eight original Member Associations banded together in 1928 as the first Federation membership, probably very few envisioned the growth of the embryo organization as it is today. Initially, the hope was for 1,000 members in the first ten years—a figure eclipsed by the membership of 2,472 and 399 non-member subscribers actually attained in the first decade. At the close of 1957, total member association membership reached 7,760 with enough non-member subscriptions to boost the total Journal readership to well over 9,000!

At the same time, we must look to the years ahead with confident expectation of continuous growth of the Federation and a fuller achievement of its objectives. Toward this goal will the officers, committee members, and staff of the Federation continually devote themselves to the best service possible to present and future Federation members.

R. E. F.

News and Notes

Of Persons and Activities in the Field of Hydrowastes

John W. Wakefield was recently appointed Director, Florida Department of Water Resources, Tallahassee, Fla. He formerly was Chief, Sewage and Industrial Wastes Section, Florida State Board of Health, Jacksonville, and is the Federation Director from Florida.

Dr. Nelson L. Nemerow has accepted a new position as Professor of Civil Engineering at Syracuse University, Syracuse, N. Y. He has served in the capacity of Associate Professor of Civil Engineering at North Carolina State College, Raleigh, N. C.

New president of the American Society of Civil Engineers is **Louis R. Howson**, consulting sanitary engineer of Alvord, Burdick and Howson, Chicago, Ill. Recently elected a vice-president was **Waldo G. Bowman**, Editor, *Engineering News-Record*.

Robert M. Pope has been appointed Chief Civil Engineer of his firm, the Guy B. Panero Engineers, New York, N. Y.

Linn H. Enslow, Editor, Water and Sewage Works, and a well-known journalist in the fields of water supply and sewage disposal, died recently. He was active in the New York Member Association and served the Federation for four years as vice-president (1937–41).

Professor Robert S. Ingols has been advanced to Head, Department of Public Health, Georgia Institute of Technology, Atlanta, Ga.

A number of recent changes among the consulting engineers have been announced.

Paul Bolton, formerly on the staff of the Iowa State Department of Health, and more recently with the U. S. Public Health Service, Kansas City, Mo., has become associated with the consulting engineering firm of Henningson, Durham and Richardson, Inc., of Omaha, Nebr.

William T. Ingram and **Bernard Newman** have formed Newing Laboratories, Inc., Islip, N. Y., to serve the sanitary engineering field.

Ben F. O'Neal, formerly sanitary engineer with the Palm Beach (Florida) County Health Department, has opened his own consulting practice in West Palm Beach, Fla.

H. E. Hudson, Jr., has been admitted as a partner in the consulting engineering firm of Hazen and Sawyer. He is located in the Detroit, Mich., office of this New York firm.

Announcement was recently made of the formation of Ludwig Engineering, Pasadena, Calif., by **Harvey F. Ludwig** and **Joseph L. Feeney**.

The consulting engineering firm of Jones, Henry and Williams, Toledo, Ohio, have announced the admittance of **Roger W. Stevens** as a partner.

The consulting firm of Weston Eckenfelder Associates has changed its name to: Roy F. Weston, Inc. **Roy F. Weston** will be the principal in the firm and **Professor Eckenfelder, Jr.**, will continue as consulting associate.

Leonard W. Steiger, Director of Research, Maywood Chemical Works, Maywood, N. J., shared in the 1957 Award for Chemical Engineering Achievement presented by the magazine, *Chemical Engineering*.

The Clay Sewer Pipe Association, Inc., Columbus, Ohio, has named **A. G. Cochran** to its presidency.

Wallace and Tiernan, Inc., Belleville, N. J., announced the promotion of **Thomas T. Quigley** to Director, Equipment Divisions; and **Russell C. Clement**, to Director of Sales for chlorination and chemical feeding equipment.

Joseph V. Swift of Dorr-Oliver, Inc., has been named manager of a new midwest sanitary sales office at Kansas City, Mo. He was with the southeastern division of the company at Atlanta, Ga.

Donald P. Schiesswohl, Assistant Editor and Executive Assistant of the Federation's headquarters staff, has resigned to accept a position with the Florida Department of Water Resources, Tallahassee, Fla.

Reviews and Abstracts*

Unit Operations Review—Ion Exchange. By R. Kunin, F. X. McGarvey, and A. L. Farren. *Ind. and Eng. Chem.*, **49**, 3 (Part II), 507 (Mar., 1957).

While the major use of ion exchange resins in sanitary engineering continues to be the treatment of water for immediate use, there is an expanding literature on the subject of waste treatment. Therefore, there is an entire section in this review devoted to this subject. It is also pointed out that ion exchangers are of major importance in the field of atomic energy for handling waste problems.

R. S. Ingols

Biological Oxidation of Some Organic Compounds. By R. Hatfield. *Ind. and Eng. Chem.*, **49**, 2, 192 (Feb., 1957).

This article reports on research work using acclimatized organisms similar to activated sludge for oxidizing alcohols, aldehydes, glycols, ketones, and acetic acid. The rate of biological utilization is reported by both COD and BOD. Values for one method of analysis failed with some compounds such as acetic acid, while the other method failed with other compounds such as acetone.

Primary and secondary alcohols and aldehydes were readily oxidized biologically while tertiary alcohols, methylal, and glycols were more resistant.

R. S. Ingols

Mass Spectrometric Determination of Volatile Solvents in Industrial Waste Water. By G. P. Happ, D. W. Stewart, and H. C. Cooper. *Anal. Chem.*, **29**, 68 (1957).

A variety of volatile organic compounds, dissolved in water at the level of parts per million, can be identified and their concentrations determined with the mass spectrometer. The compounds are swept out of solution with a stream of hydrogen from a boiling sample and are studied in the mass spectrometer in the gas phase. Only a few milliliters of sample are needed so that an apparatus may be used on a single sample or modified for a continuous liquid stream.

R. S. Ingols

Spectrophotometric Determination of Alkyl Benzene Sulfonate Detergents in Surface Water and Sewage. By J. D. Fairing and Frank R. Short. *Anal. Chem.*, **28**, 1827 (1956).

A relatively simple and sensitive method for rapid determination of the common synthetic detergent, alkyl benzene sulfonate, in water is given. The detergent is reacted with 1-methylheptylamine and extracted. The extracted salt is reacted with methylene blue for determination of density.

R. S. Ingols

Treatment of Highly Active Wastes. By C. B. Amphlett. *Atomics*, **8**, 4, 116 (Apr. 1957).

Three principal methods have been proposed to fix radioactive wastes in solid form: (a) fixation by ion-exchange followed by firing, (b) combined calcination and ion-exchange, and (c) conversion to unleachable glasses, melts, or ceramics. The author concludes that the ceramic process offers the following advantages over the ion-exchange method: (a) higher loadings can be achieved, resulting in greater economy of materials and greater reduction in volume, (b) high ratios of inactive impurities to active ions can be tolerated without danger of activity not being taken up; in the fusion process all the species other than volatile ones are

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N.W., Washington 16, D. C.

incorporated into the final product, (c) the process is much less sensitive to acid in the wastes if the volatilization of Ru is not a limiting factor, and (d) it is more versatile in that it is capable of handling slurry and solid wastes as well as solutions. In addition the ceramic process may be adapted to the production of intense sources of specific radioactive elements which are not subject to leaching. PHEA (1957)

CONRAD P. STRAUB

Colorimetric Determination of Chloride with Mercuric Chloranilate. BY J. E. BARNEY AND R. J. BERTOLACINI. *Anal. Chem.*, **29**, 1187 (1957).

The reagent solution containing mercuric chloranilate is added to a sample with chloride. The sample must have all stable cations removed before proceeding. The chloride displaces the chloranilate from the mercury and produces color as the free acid in proportion to the initial chloride content.

R. S. INGOLS

Determination of Small Amounts of Acrylonitrile in Aqueous Industrial Streams. BY G. W. DANES AND W. F. HAMNER. *Anal. Chem.*, **29**, 1035 (1957).

A method for the determination of acrylonitrile is described, based on its concentration by an azeotropic distillation with methanol coupled with a polarographic analysis. The analysis is applicable to a wide variety of samples, has no interferences, and is sensitive.

R. S. INGOLS

Radiological Safety in the Petroleum Industry. BY B. A. FRIES. *The Oil and Gas Jour.*, **54**, 81, 200 (Nov. 19, 1957).

The author reviews the practice employed in the petroleum industry to protect personnel in contact with radioactive materials. Wastes may be disposed of by burial in the ground, burial in the ocean, or disposal in public sewers. If land burial is used the area under consideration should be devoid of edible plant life. Radioactivity must not be leached from the soil, and the area must be marked against unauthorized entry. In the case of ocean burial, the wastes are collected, reduced in bulk, placed in steel barrels, covered with wet concrete mix, and sunk in the ocean. The radiation level of the outside surface of the barrel is limited to 200 mr per hour of gamma rays, and the barrels are dumped at a depth of at least 1,000 fathoms. The criteria governing discharge of radioactive materials into the sewer are: 100 mc per million gallons of sewage for isotopes with a half-life less than 30 days and 10 mc per million gallons for isotopes of half-life greater than 30 days. Some isotopes are more severely restricted. The dilutions refer to volumes of sewage in which the dilution is expected to occur. Dilutions of this order of magnitude are easy to reach but should be verified by calculation. (Abstractor's note: It would be preferable to verify the dilution by test rather than by calculation.) PHEA (1957)

CONRAD P. STRAUB

BOOKS, REPORTS, PAMPHLETS

Proceedings of the Fifth Southern Municipal and Industrial Waste Conference. Extension Div., Univ. of North Carolina, Chapel Hill, N. C. 261 pp. Price $1.50 (1957).

Technical papers on municipal, textile, chemical, and food-processing wastes.

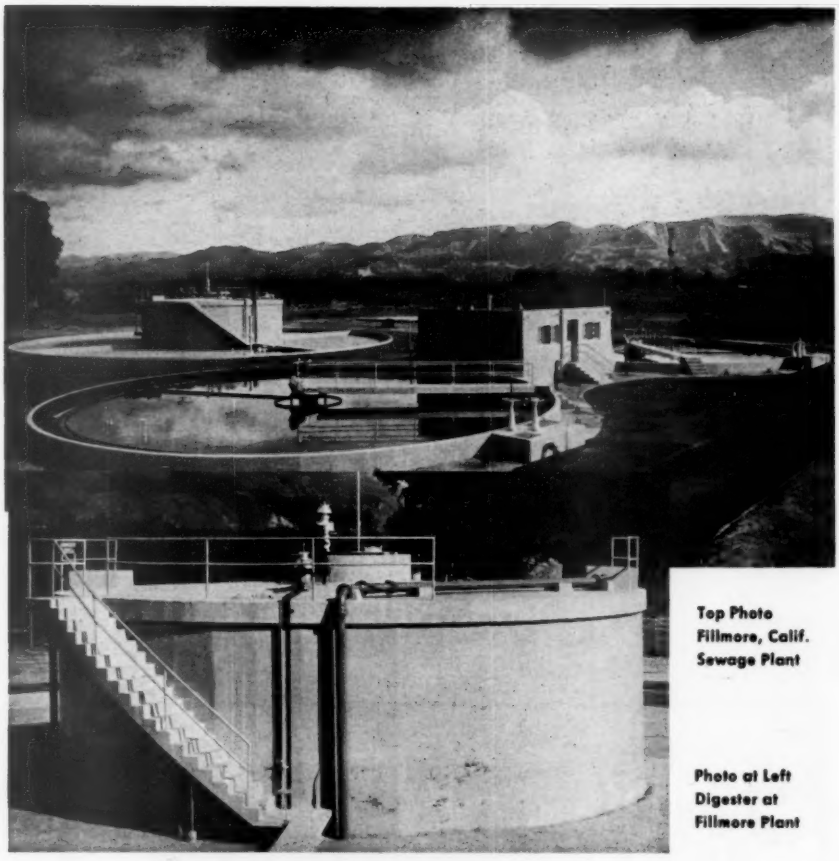
Report of the Symposium on Advanced Base Water Supply and Sanitation. Off. Tech. Services, Dept. of Commerce, Washington, D. C. 418 pp. Price $7.00 (1957).

Problems of water supply and sanitation encountered at advanced military bases as discussed by a symposium of military and civilian experts.

The Design of Storm-Water Inlets. Dept. of Sanitary Engineering and Water Resources, The Johns Hopkins Univ., Baltimore, Md. 193 pp. Price $5.00 (1956).

An extensive report devoted exclusively to inlet design. Includes rating curves, tables, nomographs, and charts.

Note: The letters "PHEA (1957)" refer to *Public Health Engineering Abstracts* for 1957. Abstract so designated is used by permission.



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Proceedings of Member Associations

GEORGIA WATER AND SEWAGE ASSOCIATION

The 1957 Annual Meeting of the Georgia Water and Sewage Association was held, as usual, in conjunction with the Georgia Water and Sewage School at the Georgia Institute of Technology, Atlanta, Ga., September 25–27, 1957. Registration for the school totaled 415, including a number of women employed in the field.

The technical program featured material typical of water and sewage short schools. A well-conducted forum was held on the design, construction, and maintenance of sewers. Another interesting portion of the program was an illustrated lecture and demonstration on corrosion.

Officers elected were as follows:

President: M. B. Nixon, Atlanta.
First Vice-President: A. B. Culberhouse.
Second Vice-President: I. C. Kelley, Atlanta.
Secretary-Treasurer: A. T. Storey, Atlanta.

A. T. Storey,
Secretary-Treasurer

NORTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

The 1957 Annual Convention of the North Dakota Water and Sewage Works Conference was held jointly with the North Central Section of AWWA at Fargo, N. Dak., September

(*Continued on page 66a*)

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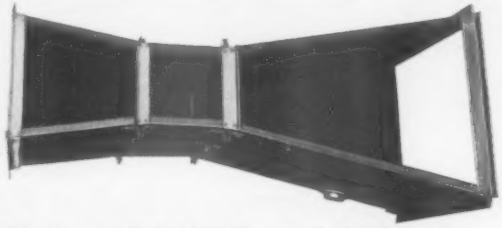

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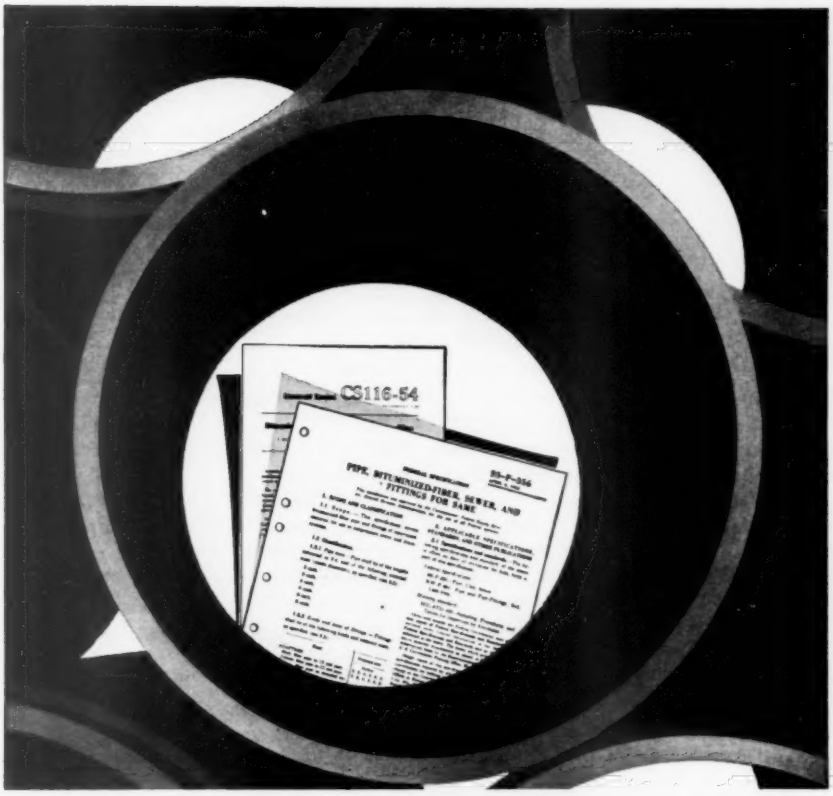

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25–27, 1957.

The technical program was conducted as a general session for water, sewage, and industrial wastes personnel. Of particular interest to sewage and industrial wastes personnel were papers on pump maintenance, federal aid for sewerage construction, Missouri River water quality, public works development in new subdivisions, and reports from state health departments. A round table discussion was held on sewage treatment plant operation.

Revitalization of the operator certification program and separation of the North Dakota Section from the South Dakota Section were discussed at the annual business meeting. The need for increased emphasis on sewer hazards was pointed out. Dickinson, N. Dak., was selected as the site of the 1958 Annual Meeting in September.

Officers elected to serve during 1957–58 were as follows:

President: L. W. Veigel, Dickinson.
Vice-President: W. Van Heuvelen, Bismarck.
Secretary-Treasurer: Richard Fuller, Southwest Fargo.

RICHARD FULLER,
Secretary-Treasurer

SOUTH DAKOTA WATER AND SEWAGE WORKS CONFERENCE

The 23rd Annual Meeting of the South Dakota Water and Sewage Works Conference was held at Sioux Falls, S. Dak., on September 11–13, 1957. A record registration of 169 was noted.

The technical program opened with a general session on topics of interest to water and sewage works personnel. A report was received on voluntary operator certification.

In the concurrent water and sewage sessions the program of interest to sewage and industrial wastes personnel featured an industrial wastes panel, an operator's discussion period, and a paper on sewage stabilization pond studies.

The program concluded with inspection trips to the Sioux Falls sewage treatment plant, the Morrell and Company industrial waste facilities, and the Greenlee Packing Company waste stabilization pond.

At the Annual Banquet, Conference awards were made as follows: Izaak Walton League Plaque to Ray Gartner, Superintendent, Water and Sewage Works, Burke, and the Longevity Award to Roy Baker, City Engineer, Pierre.

At the business luncheon the following officers were elected for 1956–57:

President: Roy Heiens, Philip.
Vice-President: Alfred Ross, Huron.
Secretary-Treasurer: Don C. Kalda, Pierre.

DON C. KALDA,
Secretary-Treasurer

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(Continued through page 74a)

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INDEX TO ADVERTISERS

	Page
American Concrete Pressure Pipe Association	46a, 47a
Armco Drainage & Metal Products, Incorporated	59a
Brown Company	65a
Builders-Providence, Incorporated, Division of B-I-F Industries, Incorporated	Inside Front Cover
Cast Iron Pipe Research Association	50a, 51a
Chicago Pump Company	39a
Cloroben Chemical Corporation	48a
Combustion Engineering (Raymond Division)	41a
Dorr-Oliver Incorporated	62a
Filtration Equipment Corporation	64a
Flexible Incorporated	76a
Homestead Valve Manufacturing Company	53a
Inertol Company, Incorporated	58a
Infilco Incorporated	45a
Lock Joint Pipe Company	Inside Back Cover
Minneapolis-Honeywell Regulator Company	49a
National Clay Pipe Manufacturers, Incorporated	57a
Pacific Flush Tank Company	60a
Simplex Valve and Meter Company	43a
United States Pipe and Foundry Company	54a, 55a
Vapor Recovery Systems Company	63a
Walker Process Equipment Incorporated	56a
Wallace & Tiernan Incorporated	Back Cover
Wheeler, C. H., Manufacturing Company (Economy Pump Division)	52a
Zimmer and Francescon	66a

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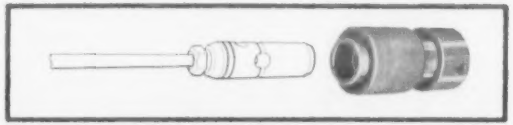

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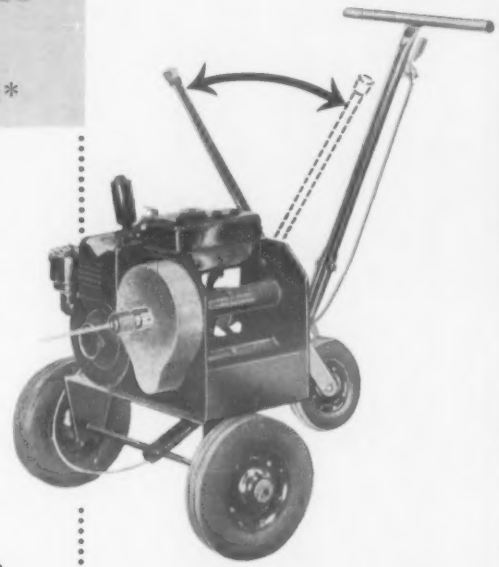

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